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# TREATMENT OF TEXTILE WASTEWATER BY ACTIVATED SLUDGE AND ALUM COAGULATION

Thomas L. Rinker

Blue Ridge-Winkler Textiles

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# TREATMENT OF TEXTILE WASTEWATER BY ACTIVATED SLUDGE AND ALUM COAGULATION

by

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Mr. Gerald Houck, Environmental Chemist at BRW, was responsible for the analytical and laboratory research work for the project.

EPA Project Officer for the study was Mr. Thomas N. Sargent of the EPA Southeast Environmental Research Laboratory in Athens, Georgia.

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# SECTION I

## CONCLUSIONS

Blue Ridge-Winkler Textiles, Bangor, Pennsylvania, conducted a one-year demonstration project of its wastewater treatment plant for the United States Environmental Protection Agency.

The demonstration project involved monitoring the performance of the activated sludge-alum coagulation treatment system, collecting production data for correlation with wastewater data, and conducting basic research regarding treatment process improvement.

An analysis of the operating and research data gathered during the course of the grant project has produced these following conclusions.

1. The wastewater was found to contain a significant quantity of (a) degradable and refractory organic chemicals, (b) soluble and colloidal dyestuffs, (c) nitrogen and phosphorous and (d) certain heavy metals.

   Median values for wastewater flow, BOD, COD, and color were 0.53 MGD, 448 mg/l, 1,553 mg/l, and 1,032 APHA units, respectively.

2. The treatment system, consisting of an activated sludge process and an alum coagulation process operating in series, was found to be capable of producing a high quality effluent from a textile mill producing knit synthetic fabric for the apparel and automotive upholstery trades.

3. The activated sludge process was determined to be an effective mechanism for removal of soluble, degradable organic chemicals and ammonia nitrogen when operated with a mixed liquor suspended solids level of 2928 mg/l and a 14.4 hour residence time. Removals of BOD, COD, color, and ammonia nitrogen were 78 percent, 42 percent, 30 percent, and 73 percent, respectively.

4. The alum coagulation process was determined to be an effective mechanism for removal of colloidal organic chemicals (including dyes), suspended solids, orthophosphate, chromium, copper, and zinc when operated with an alum dosage of 262 mg/l and a pH of 6.2. Removals of BOD, COD, color, suspended solids, and orthophosphate were 75 percent, 58 percent, 58 percent, 70 percent and 70 percent, respectively.

5. Removals of BOD, COD, color, and suspended solids by the total treatment system were found to be 94 percent, 76 percent, 71 percent, and 40 percent, respectively.

   Effluent concentrations of BOD, COD, color, and suspended solids based on these removal percentages were found to be 25 mg/l, 380 mg/l, 303 APHA units, and 104 mg/l, respectively.

   Effluent contaminant to production weight ratios for BOD, COD, and suspended solids based on these removal percentages were found to be 2.22 lbs/1000 lbs (kg/kkg), 34.05 lbs/1000 lbs (kg/kkg), and 9.31 lbs/1000 lbs (kg/kkg), respectively.

6. Mathematical models and graphical representations of the performance data predicting performance of the total system under a variety of influent wastewater and operating conditions, was accomplished for both the activated sludge and alum coagulation processes.

7. The activated sludge system was found to generate 943 pounds (428 kilograms) of solids per day, and the alum coagulation system was found to generate 1347 pounds (612 kilograms) of solids per day. These solids were successfully dewatered from a feed solids concentration of 1.50 - 1.75 percent to a discharge solids concentration of 10.0 - 15.0 percent using a horizontal solid bowl centrifuge with a cationic polymer additive.

8. Operating cost of the system was determined to be $269,030 per year or $1.65 per thousand gallons ($0.43 per cubic meter) treated. Capital cost was determined to be $1,150,000 for a 1.25 million gallon (4731 cubic meter) per day capacity system. Operating cost for a system operating at capacity was estimated to be $1.20 per thousand gallons ($0.32 per cubic meter) treated, and $0.014 per pound ($0.03 per kilogram) of product.

9. Research indicated that performance of the alum coagulation system could be optimized if the process were carried out using two step neutralization and dual media final filtration. Effluent COD, suspended solids, and color values would be 300 mg/l, 25 mg/l, and 200 APHA units respectively. The increase in operating cost for this modification would be $13,000 per year or $0.04 per design thousand gallons ($0.01 per cubic meter), and the increase in capital cost was estimated at $200,000 for a 1.25 million gallon (4731 cubic meter per day) capacity system.

10. The treatment system, even with a modification of the alum coagulation system to a two-step process, would not be capable of removing refractory organic material or soluble dyestuffs to levels sufficient to meet probable future discharge standards.

11. For removal of soluble color only, pilot investigation indicated that ozone oxidation following alum coagulation was the least costly process available. This process would yield a color level of 50 to 75 APHA units using a 10-15 mg/l dosage and a 5 to 10 minute reaction time when run at a wastewater pH of 5.0. Operating cost of the process would be an additional $37,000 per year or $0.10 per design thousand gallons ($0.03 per cubic meter) treated, and capital cost of the ozone system equipment would be an additional $250,000 for a 1.25 million gallon (4731 cubic meter) per day system.

12. For an activated sludge/alum coagulation/ozonation/filtration system designed for 1.25 million gallon (4731 cubic meter) flow, the operating cost would be $1.34 per thousand gallons treated ($0.36 per cubic meter. Capital cost for the system was estimated to be $1,600,000.

13. Chlorine or hydrogen peroxide oxidation were found not to be effective for residual soluble color removal except at high dosages or under special conditions.

14. For removal of refractory organic material and color, a columnar adsorption process using either granular activated carbon or polymeric and ion exchange resins would be required as determined by bench scale investigations. Capital costs for the carbon and resin systems were estimated to be $636,000 and $836,000, respectively, for a 1.25 million gallon (4731 cubic meter) per day facility.

Operating cost of the systems was estimated to be $0.44 per 1000 gallons ($0.12 per cubic meter) treated for the carbon process and $0.48 per 1000 gallons ($0.13 per cubic meter) treated for the resin.

15. The addition of powdered activated carbon to the activated sludge system was found to appreciably increase BOD removal capacity but did not result in additional color reduction.

16. The total production level averaged 48,400 pounds (22,000 kilograms) per day and wastewater was produced at the rate of 12.05 gallons per pound of product (0.10 cubic meter per kilogram). Pressure beam dyed production of a nylon/arnel blend fabric was found to account for 53.4 percent of total yearly production. A graphical representation of the effect of beam production on wastewater flow, COD, and color was accomplished with the result that the waste load to the treatment system could be predicted based on beam production.

# SECTION II

## RECOMMENDATIONS

The following recommendations are in order following a review of the results and conclusions of the study.

1. The performance of a full-scale two-step alum coagulation process using dual media filtration for final suspended solids removal, and a full-scale ozonation system for residual, soluble color removal should be demonstrated.

2. The potential for partial re-use of wastewater from an activated sludge/alum coagulation/ozonation/filtration system should be defined by a demonstration project using laboratory and pilot-scale production machinery.

3. The chemistry of the alum coagulation process should be investigated in detail by a laboratory research project to determine the factors affecting wastewater contaminant removal in order that the process may be more confidently applied for wastewater treatment in the textile industry.

4. Cost projections of the alum coagulation process as an addition to an activated sludge system should be made.

5. A long-term research project should be initiated to determine the cost and adverse environmental affects of dewatering and disposing of sludge from an activated sludge/alum coagulation system.

6. The residual chemicals remaining in textile wastewaters after activated sludge and alum coagulation treatment needs to be defined in order to allow for additional waste reduction by consideration of in-plant changes.

7. Standard procedures need to be developed for evaluation of the treatability of production chemicals by common wastewater processes and for the assessment of the potential impact on the aquatic environment of the residual amounts of these chemicals remaining after treatment.

# SECTION III

# INTRODUCTION

## PERSPECTIVE

The textile industry in the United States is one of the country's major users of water as a basic raw material in the manufacturing processes. This industry segment accounts for about one percent of all the aqueous industrial discharge after the water has been used as a conveyor for the chemicals and dyestuffs associated with converting raw fibers into finished fabrics. The waste discharge is significant not only in volume but also in the concentration and complexity of the contaminants that may be present. Because the textile industry and its effluents are so diverse, it is helpful to view the industry not simply as a group of fiber processors but as a large number of unique chemical processing plants using a wide range of fibers, chemicals, dyestuffs, water, machinery, and flow sheets to produce a final fabric. Each individual plant's discharge can result in the addition to the nation's waterways of significant quantity of degradable and non-degradable organics, nutrients, heavy metals, toxic agents, and inorganic salts. The discharges contain both conspicuous pollutants such as color and foam producing material and insidious pollutants such as trace metals and organics.

One method that may be used to distinguish the segments of the textile industry is to analyze production in terms of fiber type. Historically the natural fibers have constituted the bulk of yearly production in this country, but recently the advent of man-made (synthetic) fibers has resulted in an increasingly larger share of total production going to production of new synthetic fibers and to production of knit fabric. For example, there has been a 286 percent growth in knit synthetics, a 381 percent growth in woven synthetics, and a 12 percent decline in cotton woven production since 1958.(9) Rayon was the first synthetic and it was shortly followed by the cellulose acetates, nylon, polyester and acrylic. In the last few years the list of synthetic fibers being manufactured has dramatically increased. Figure I illustrates the sharp increase in synthetic fiber consumption compared with the natural fibers, and Table I projects the growth of synthetics for the next five years.

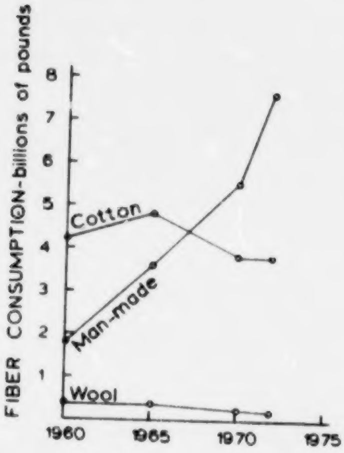


FIGURE I. U.S. fiber consumption(9)

## TABLE I

## GROWTH RATES OF TEXTILE FIBERS(6)

PERCENT INCREASE (DECREASE) FROM PREVIOUS PERIOD

1970 BASE YEAR

| FIBER | 1972 | 1974 | 1976 | 1978 |
|---|---|---|---|---|
| COTTON | 13.9 | (2.3) | (2.2) | (2.4) |
| WOOL | (3.8) | (4.0) | 0 | (4.2) |
| NYLON | 49.2 | 20.1 | 14.6 | 17.2 |
| ACETATE | (11.6) | 0 | 2.6 | 2.6 |
| POLYESTER | 39.5 | 26.0 | 22.3 | 18.1 |
| ACRYLIC | 21.7 | 14.2 | 12.5 | 11.4 |
| RAYON | (2.0) | (6.2) | (6.6) | (5.9) |

This growth in the synthetic fiber portion of the textile industry has resulted in significant changes in dye and chemical use and in process flow sheets.

In the case of dyes, there has been a marked increase in the quantity of dyes used in processing synthetics while the use of dyes associated with natural fibers has declined. This data is illustrated in Table II.

## TABLE II

## DYESTUFF USE AND GROWTH(6,7)

| DYESTUFF | COTTON | WOOL | FIBER ACETATE | POLYESTER | NYLON | RAYON | PERCENT OF TOTAL USE | PERCENT GROWTH 1973-1978 |
|---|---|---|---|---|---|---|---|---|
| ACID | | X | | | X | | 10 | 6.3 |
| AZOIC | X | | | X | | X | 3 | - |
| BASIC | | | X | X | X | | 6 | 7.2 |
| DIRECT | X | | | | | X | 17 | 2.8 |
| DISPERSE | | | X | X | X | | 15 | 9.7 |
| FIBER-REACTIVE | X | | | | X | | 1 | 8.2 |
| SULFUR | X | | | | | X | 10 | - |
| VAT | X | | | | | X | 26 | (3.5) |

With the development of polyester, a new group of auxiliary chemicals - carriers - were introduced to allow the use of available dyes and equipment. The trend to synthetics has also resulted in the increased use of dyebath auxiliaries for leveling, penetration, fastness, softness, and several other uses. An increased emphasis on durability has resulted in the increased use of finishes for softness, water repellency, soil release, fire retardancy, and lubrication for mechanical finishing. These new chemicals represent a broad range of organic/inorganic chemicals and are a major reason for the diversity of wastewater characteristics in the industry.

Smilarly, new equipment such as beam dyers, pressure becks, and jet dyers have been developed as improvements on the basic atmospheric beck in order to economically produce the new fibers using available dyes.

The United States Environmental Protection Agency (EPA) has segmented the industry as follows for the purpose of developing industry discharge guidelines as mandated by the 1972 Water Pollution Control Act Amendments:(8)

A. Wool scouring  
B. Wool finishing  
C. Dry processing  
D. Woven fabric finishing  
E. Knit fabric finishing  
F. Carpet mills  
G. Stock and yarn dyeing and finishing

Of the approximately 7100 textile plants in this county, approximately 1300 mills include wet processing operations and are part of the EPA classifications. Approximately seventeen percent are in the knit finishing segment, category "E" of the EPA effluent guideline categories.(9) This segment of the industry is relatively new, with significant production beginning in the early 1960's.

The textile industry over the last several decades has concentrated its growth in the southeastern section of the country. For the knit fabric finishing category, approximately twenty-eight percent of the mills are now located in this geographical area with approximately sixty percent of the goods for this category produced by these mills.(9) Given the demographic pattern of smaller communities in this area and the likelihood that these communities have limited funds for wastewater treatment facilities, it can be expected that industry owned treatment facilities will be the available method of obtaining adequate treatment of the wastewater prior to discharge.

Although no data are available, it is generally recognized that a significant number of mills in the textile industry are not part of large parent corporations but are part of small companies. If the number of employees is used as a guide to illustrate this fact, approximately thirty-six percent of the knit fabric finishing category mills employee less than fifty people.(9) These mills have limited resources for supplying the capital for equipment or for retaining expert advice for problems of environmental control. As a result, these firms depend heavly on industry associations and governmental agencies for direction in abating air and water pollution.

## TREATMENT REQUIREMENTS

Increasing public awareness of environmental issues has resulted in increasing attention to water pollution control measures for all of industry. In particular, environmental concern was sharply focused on industry with the passage of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500). Among the requirements of this legislation is the mandate for implementation of the "best practicable control technology currently available" by 1977, "best available control technology economically achievable" by 1983, and the establishment of a national goal of "zero discharge of pollutants" by 1985.

The historic method of textile wastewater treatment is by biological processes in either public or private systems as illustrated in Table III.

### TABLE III

### TEXTILE INDUSTRY WASTEWATER TREATMENT IN 1972(7)

| | |
|---|---|
| TO MUNICIAL TREATMENT SYSTEMS | 35% |
| PRIMARY TREATMENT ONLY | 5% |
| SECONDARY TREATMENT | 45% |
| NO TREATMENT | 15% |

In January, 1974, when the EPA published the tentative discharge guidelines for the industry, it chose activated sludge as the model for best practicable treatment, currently available (BPTCA) technology. For the best available treatment, economically achievable (BATEA) technology, the EPA again selected activated sludge in combination with a tertiary treatment process.(7) Essentially, the criteria proposed by the guidelines seek to limit only the gross organic content of the wastewater as indicated by BOD, COD, and suspended solids values. The American Textile Manufacturers Institute (ATMI), while agreeing with the selection of the processes for the treatment models, judged the tentative guidelines as too restrictive and proposed an alternate set of values.(3) The final EPA industry guidelines were published in the Federal Register on July 5, 1974.(7) These several sets of guidelines for industry category "E" are summarized in Table IV.

## TABLE IV

## FEDERAL EFFLUENT GUIDELINES CATEGORY E

| PARAMETER | EPA BPTCA PROPOSED | EPA BPTCA FINAL | EPA BATEA PROPOSED | EPA BATEA FINAL | ATMI BPTCA |
|---|---|---|---|---|---|
| | (POUNDS/1000 POUNDS OR K/KKG OF PRODUCT) | | | | |
| BOD | 1.8 | 2.5 | 1.2 | 1.7 | 4.0 |
| COD | 24.0 | 40.0 | 6.4 | 13.3 | 40.0 |
| SUSPENDED SOLIDS | 8.0 | 10.9 | 5.3 | 1.7 | 6.0 |

Several states, particularly in the northeastern area of the country, had adopted prior to the issuing of the federal guidelines either effluent or stream criteria which limited discharges in the content of nutrients, metals, color, or foam producing material. It can be anticipated that the implementation of similar criteria will continue to spread among the states and will become increasingly important to the industry, particularly if stream limited (the discharge is a significant portion of the design stream flow) criteria apply. The latest Pennsylvania discharge criteria for a stream limited textile discharge are presented in Table V. Regional agencies such as the Delaware River Basin Commission (DRBC) have also been increasingly active in setting criteria and have also adopted restrictions limiting discharges.

### AVAILABLE TECHNOLOGY

Wastewater treatment practice for the textile industry has been concerned almost exclusively with the removal of degradable organic material by biological treatment processes. However, with the changing nature of textile wastewaters, considerable work needs to be done to demonstrate through long term projects the efficiency of other available treatment methods. The most critical need is to evaluate those processes which could be added to an activated sludge treatment system already in existence in order to minimize capital requirements while providing for removal of additional contaminants.

## TABLE V

## DISCHARGE CRITERIA FOR A TEXTILE MILL IN PENNSYLVANIA

| PARAMETER | AVERAGE VALUE | MAXIMUM VALUE |
|---|---|---|
| PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL RESOURCES | | |
| BOD (MG/L) | 25 | 50 |
| SUSPENDED SOLIDS (MG/L) | 25 | 50 |
| DISSOLVED SOLIDS (MG/L) | - | 1000 |
| AMMONIA NITROGEN (MG/L) | 2.0 | 4.0 |
| TOTAL PHOSPHOROUS (MG/L) | 1.5 | 3.0 |
| COLOR (APHA) | 60 | - |
| OIL AND GREASE (MG/L) | 10 | 15 |
| PHENOL (MG/L) | 0.05 | 0.10 |
| FOAM | NO FOAM 50 YARDS | BELOW DISCHARGE |
| CHROMIUM (MG/L) | 0.09 | 0.18 |
| ALUMINUM (MG/L) | 1.0 | 2.0 |
| IRON (MG/L) | 0.75 | 1.5 |
| ZINC (MG/L) | 0.3 | |
| DELAWARE RIVER BASIN COMMISSION | | |
| BIOASSAY | | LESS THAN 50% MORTALITY AFTER 96 HOURS AT A 1:1 DILUTION |
| BOD | 95% REMOVAL | |
| SUSPENDED SOLIDS | 90% REMOVAL | |
| DISSOLVED SOLIDS | | 33 1/3% INCREASE IN STREAM LEVEL |

Historically, most of the reported data for textile wastewater treatment has considered effluents from textile plants producing primarily natural fabrics. Clearly there is a need for data from a mill producing widely used synthetic fabrics in order to better characterize this particular type of wastewater. In order for such single plant information to be effective in promoting the level of knowledge in this industry segment, wastewater data needs to be correlated with definitive production data.

Blue Ridge-Winkler Textiles, (BRW), A Divison of Lehigh Valley Industries, Inc., was faced in the late 1960's with meeting new, strict discharge criteria imposed by the Commonwealth of Pennsylvania's Department of Environmental Resources on its Bangor Plant. This plant produces simplex, tricot, and circular knit synthetic fabric for the apparel and automotive upholstery trades. A research program to evaluate alternate treatment processes was begun by BRW in 1969.

Based on the performance characteristics of the then available and demonstrated technology, BRW decided to use a system composed of an activated sludge process and an alum coagulation process operating in series. This system would result in the removal of degradable organics and some nutrients by biological oxidation in the activated sludge process, and in the removal of metals, colloidal organics, and additional nutrients and soluble organics by coagulation or precipitation in the alum coagulation process.

## DEMONSTRATION GRANT

Realizing the importance of the demonstration of this new technology to the textile industry, BRW sought and obtained an Environmental Protection Agency Demonstration Grant (EPA Grant S801192). The grant would provide sufficient funding so that the treatment system could be evaluated in detail over a one-year period of plant operation in order to fully define the system capability. Also, production data would be considered as a significant parameter in the evaluation of system performance. The specific objectives of the grant project were as follows:

- Characterize the raw waste,
- Characterize the mill production in terms of fibers, chemicals, and processes
- Determine the operating characteristics of each unit treatment process,
- Establish the treatment capabilities of the total system under various raw waste compositions,
- Correlate operating characteristics of the system with the production characteristics,
- Determine the cost of treatment, and
- Determine what alternative processes would be available to provide additional treatment, if required.

# SECTION IV

# DESCRIPTION OF THE MANUFACTURING FACILITY

## PART A - FABRICS PROCESSED

### Present Mix And Volume

During the study period, daily records of production volume were kept by fabric construction and by processing equipment type. Tables XIII and XIV summarize this data and Figure II presents part of the data graphically.

The data presented is in units of pounds of fabric dyed per day. Since the production pipeline at BRW is relatively short and continuous, this data is effectively the pounds and fabric dyed and finished per day.

One of the variables in the production process is fabric yield - the ratio of yards to pounds of fabric. For the present mix this ratio varies from style to style within the range of 1.0 (automotive) to 4.25 (lingerie). Also, this ratio will vary during production as the product is alternately shrunk (during dyeing) and stretched (during drying). Therefore, it was decided to use the pound method of reporting since dye and finish formulas, as well as federal discharge limitations are based on fabric weight.

As indicated by the data, the largest segment of the BRW product line is velour fabric manufactured for the apparel trade. The fabric is an arnel/nylon blend and represents 56.0 percent of the total yearly production. It is dyed primarily on pressure beam equipment which represents 53.8 percent of the total yearly production. As illustrated in Figure V, it was possible to correlate total, daily mill production with daily beam production. Other significant fabrics include nylon (13.2 percent) for the automotive and lingerie trades and polyester/nylon blends (13.0 percent) for the uniform trade.

## TABLE VI

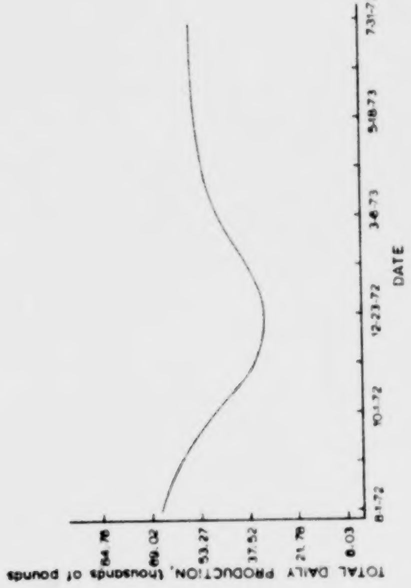
## SUMMARY OF PRODUCTION DATA BY FABRIC CONSTRUCTION

| FABRIC CONSTRUCTION | NUMBER OF DAYS PROCESSED DURING YEAR | YEARLY AVERAGE OF DAILY PRODUCTION (POUNDS) | YEARLY MEDIAN OF DAILY PRODUCTION (POUNDS) | LOW MONTHLY AVERAGE OF DAILY (POUNDS) | HIGH MONTHLY AVERAGE OF DAILY (POUNDS) | FRACTION OF TOTAL YEARLY PRODUCTION (PERCENT) |
|---|---|---|---|---|---|---|
| ARNEL | 153 | 1,439 | 960 | 377 | 3,259 | 1.6 |
| NYLON | 276 | 6,851 | 6,720 | 4,201 | 8,750 | 13.2 |
| ARNEL/NYLON | 278 | 28,791 | 29,600 | 10,206 | 41,761 | 56.0 |
| NYLON/POLYESTER | 228 | 8,138 | 7,680 | 2,821 | 13,764 | 13.0 |
| QIANA | 269 | 1,857 | 1,800 | 1,130 | 2,857 | 3.5 |
| ACETATE/NYLON | 53 | 3,350 | 3,320 | 121 | 9,587 | 1.2 |
| ANTRON | 223 | 2,202 | 1,280 | 895 | 3,900 | 3.4 |
| DACRON | 151 | 1,634 | 1,024 | 463 | 3,071 | 1.7 |
| OTHER | - | - | - | - | - | 6.4 |

## TABLE VII

## SUMMARY OF PRODUCTION DATA BY MANUFACTURING PROCESS

| PROCESS | YEARLY AVERAGE OF DAILY PRODUCTION (POUNDS) | YEARLY MEDIAN OF DAILY PRODUCTION (POUNDS) | LOW MONTHLY AVERAGE . OF DAILY PRODUCTION (POUNDS) | HIGH MONTHLY AVERAGE OF DAILY PRODUCTION (POUNDS) | FRACTION OF TOTAL YEARLY PRODUCTION (PERCENT) |
|---|---|---|---|---|---|
| PRESSURE BEAM | 25,829 | 27,040 | 7,884 | 36,348 | 53.8 |
| ATMOSPHERIC | | | | | |
| BECK | 14,837 | 14,300 | 11,005 | 19,974 | 28.5 |
| PAD | 9,03L | 8,880 | 4,299 | 11,969 | 17.7 |
| TOTAL PRODUCTION | 48,127 | 48,400 | 34,349 | 56,560 | 100.0 |



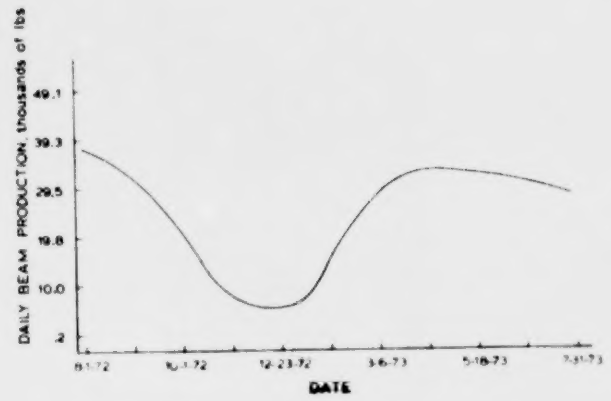


**FIGURE II.** Chronological plot of daily production values

**FIGURE III.** Chronological plot of daily beam production values

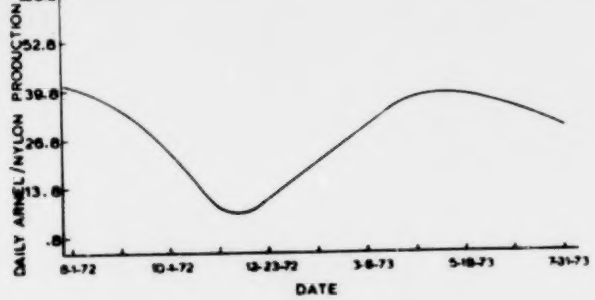


**FIGURE IV.** Chronological plot of daily arnel/nylon production values

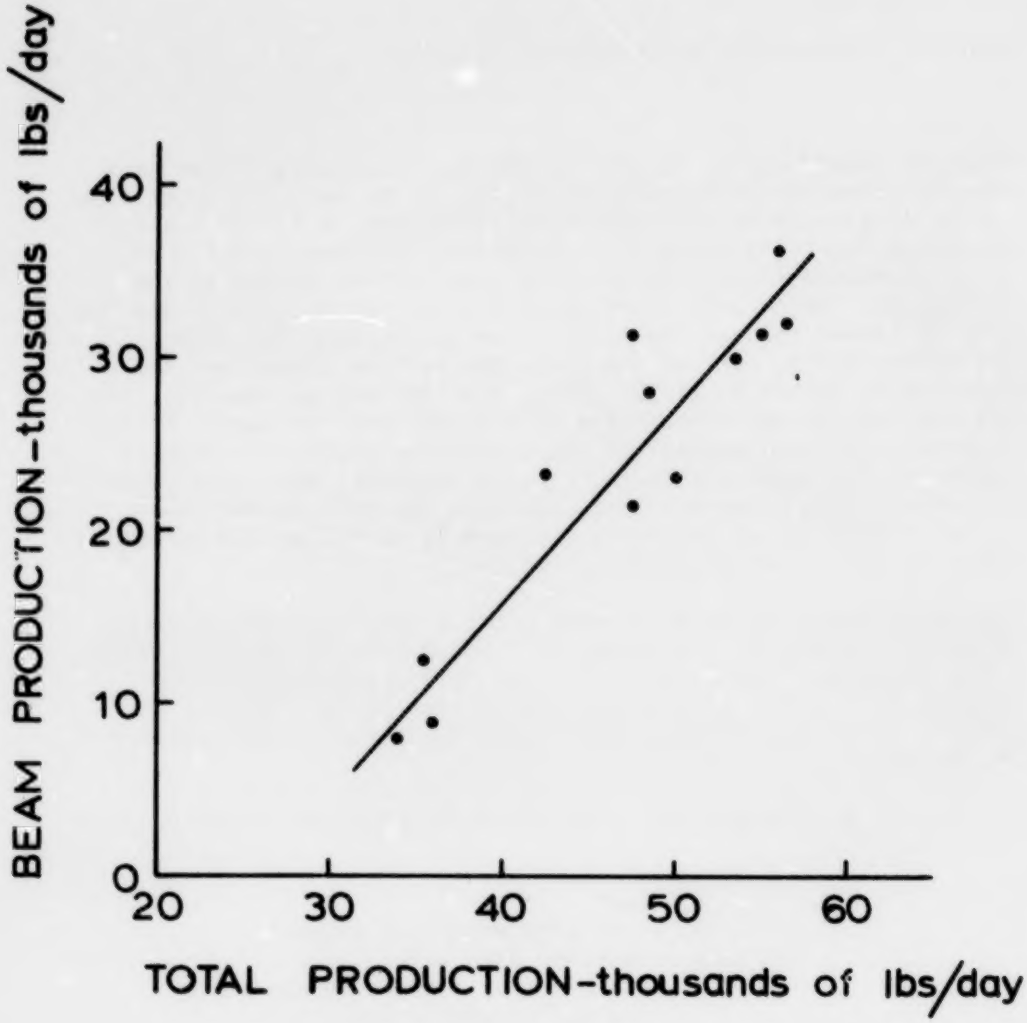


**FIGURE V.** Correlation of beam production to total production

## PART B-1 - MANUFACTURING OPERATIONS: DYEING

Pressure (beam) dyeing is used at BRW for processing tricot knit fabrics primarily of nylon/arnel blends in the velour product line. In the first step of this operation (batching), a specific weight of greige fabric is wound on a perforated stainless steel beam using a predetermined tension. The beam is then placed in the rectangular dyeing unit (Burlington Engineering Co., Inc.) and the bath is forced through the hollow beam and through the cloth. During the dyeing part of the cycle the unit is closed and the temperature raised to 116°C. Also, the flow may be reversed, and the dye bath pulled through the fabric and into the beam. At the conclusion of each segment of the production cycle, the bath is dumped to the sewer and during rinsing segments, the rinse water is pumped through the beam and overflows the unit to the sewer. At the conclusion of the cycle the beam is withdrawn and additional water is removed on a vacuum extractor.

The production complement of beam dyers at BRW consists of three, 2500 pound (1135 kg) and three, 1000 pound (454 kg) nominal fabric capacity units. The larger units can hold approximately 3000 gallons (11.3 cubic meters) and the smaller units 1,200 gallons (4.5 cubic meters) not considering volume displacement by the fabric.

A typical six to eight hour production sequence for the beam dyers is as follows:

1. Load
2. Fill with water and steam
3. Overflow with water
4. Add carrier, dispersing agent and Dyeing assistants and run
5. Add dye mix
6. Close lid and elevate temperature and run
7. Cool and dump dyebath
8. Fill with water and steam
9. Add scour chemical and run
10. Overflow with water
11. Dump
12. Repeat steps 8 through 11
13. Unload

The process flow for the pressure beam dyeing operation is illustrated in Figure VI.

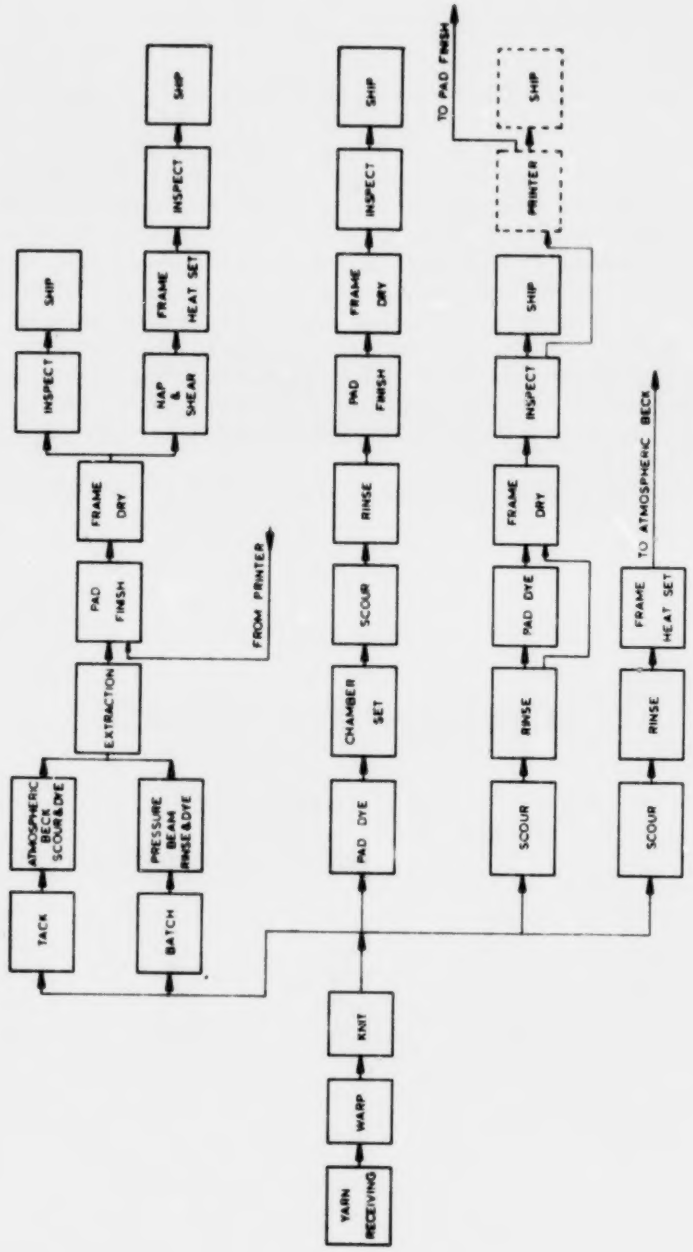

YARN RECEIVING
WARP
KNIT
TACK
ATMOSPHERIC BECK SCOUR & DYE
BATCH
PRESSURE BEAM RINSE & DYE
EXTRACTION
PAD FINISH
FROM PRINTER
FRAME DRY
INSPECT
SHIP
NAP & SHEAR
FRAME HEAT SET
INSPECT
SHIP
PAD DYE
CHAMBER SET
SCOUR
RINSE
PAD FINISH
FRAME DRY
INSPECT
SHIP
SCOUR
RINSE
PAD DYE
FRAME DRY
INSPECT
SHIP
PRINTER
SHIP
TO PAD FINISH
SCOUR
RINSE
FRAME HEAT SET
TO ATMOSPHERIC BECK

FIGURE VI. Manufacturing process flow sheet

## Atmospheric Beck Dyeing

Atmospheric beck (tub) dyeing is used at BRW for processing tricot, simplex, and occasionally circular knits of nylon, arnel, and polyester fibers in all product lines. In this operation a length of greige fabric (piece) is threaded over an oval shaped reel at the top of the beck, (Rodney Hunt Co.), and the ends of the piece are sown together to form a continuous loop (rope). This rope is then circulated through the bath as the reel turns with, at any time, approximately 90% of the fabric in the bath and 10% in the atmosphere. The dye bath and other segments of the production cycle are run at 100°C. At the end of each segment, the bath is dumped to the sewer, and during the rinsing segments, the rinse water overflows the unit. At the conclusion of the cycle, the piece is withdrawn and additional water is removed by a centrifugal extractor.

The production complement of atmospheric becks at BRW is presented in Table VIII.

### TABLE VIII

### ATMOSPHERIC BECKS IN PRODUCTION

| NUMBER OF UNITS | LENGTH (FEET) | LENGTH (METER) | NOMINAL FABRIC CAPACITY (POUNDS) | NOMINAL FABRIC CAPACITY (KILOGRAMS) | NOMINAL WATER VOLUME (GALLONS) | NOMINAL WATER VOLUME (CUBIC METERS) |
|---|---|---|---|---|---|---|
| 3 | 2 | 0.6 | 50 | 23 | 330 | 1.2 |
| 3 | 3 | 0.9 | 150 | 68 | 490 | 1.8 |
| 2 | 5 | 1.5 | 400 | 182 | 820 | 3.1 |
| 6 | 8 | 2.4 | 600 | 272 | 1,300 | 4.9 |
| 14 | 14 | 4.3 | 1,000 | 454 | 3,900 | 14.8 |

Typical six to twelve hour production sequences for the atmospheric becks are as follows:

1. Load
2. Fill with water and steam
3. Add scour chemicals
4. Elevate temperature and run
5. Overflow with water and steam
6. Dump
7. Fill with water and steam and run
8. Dump
9. Fill with water and steam
10. Add pH adjustment chemical and run
11. Dump
12. Fill with water and steam
13. Add carrier, dispersing agent, dyeing, assistants, ph control chemicals, or sequestering chemicals as appropriate and run
14 Add dye mix
15. Elevate temperature and run
16. Cool and dump dyebath
17. Fill with water and steam and run
18. Dump
19. Fill with water and steam and run
20. Dump

Alternate A (nylon;lingerie)

21B Fill with water and steam
22B Add fixing chemicals
23B Elevate temperature and run
24B Dump
25B Fill with water and steam and run
26B Dump
27B Fill with water and steam and run
28B Dump

Alternate B (nylon;automotive)

Delete 5 through 12
5D Cool using cold water
6D Dump
7D Fill with water and steam
8D Add pH control chemical
9D Elevate temperature and run
10D Cool using cold water
11D Dump
12D Fill with water and steam
21A Through 26A

The process flow for the atmospheric beck dyeing operation is illustrated in Figure VI.

## Pad Dyeing

Pad dyeing is used at BRW for processing tricot and simplex knit fabrics of nylon/polyester blends in the uniform product line. The nature of the equipment limits dyeing to light shades on a limited number of fabrics. In this production operation, the greige fabric is continuously fed into the pad unit in a wide form from a roll. The pad unit consists of a dye bath and a set of squeeze rolls. As the fabric passes through the padder the dye is applied to the surface on both sides of the material and the excess removed by the rolls. The dye solution is maintained at a constant level in the padder during processing in order to keep the dye concentration constant. From the padder, it is fed through an infrared drying chamber then to a chamber. In order to achieve dye penetration, the chamber is set aside for two to four hours while steam is applied. After this period, the roll is removed and sent through the finishing step. The only water discharge from this operation is the remaining full strength dye solution in the padder and the equipment wash down.

BRW has one pad dyer (American Artos Inc.) in its production complement. This unit has the capability of handling 1500 pounds (681 kg) per hour of fabric and uses a 30 gallon (0.11 cubic meters) pad bath.

The process flow for the pad dyeing operation is illustrated in Figure VI.

## Dye Kitchen

In Mill Number One all dyes and chemicals are hand carried from the dye kitchen to the becks and beam dyers. A typical dye mix is prepared in a portable, thirty gallon mix tank in the dye kitchen by adding precisely weighed quantities of the dye powder or concentrate to water. The mix tank is then wheeled to the appropriate dye unit and the mix transferred. The mix tank is then flushed clean with the flush water being directed into the dye unit. This procedure is typical of all operations in the dye kitchen area and results in very little wastewater.

In Mill Number Two, the dye and chemical solutions are transported by pipeline from the dye kitchen to the production units. After each run, the mixers and pipelines must be cleaned by flushing first with a solvent cleaner and then with water.

PART B - 2 - MANUFACTURING OPERATIONS: FINISHING

## Drying And Heat Setting

Drying and heat setting of fabric at BRW is accomplished using four totally enclosed pin tenter frames of varying widths (Kenyon Co., American Artos Inc.).

Two tenter frames are used almost exclusively for drying dyed fabric. In this operation, the fabric is fed in an open form through a padder, where a finish is applied, and then into the drying oven. The pad bath volume is 215 gallons (0.81 cubic meters). The solution is made in sufficient strength initially to insure an adequate concentration at the end of a run or is fed through a reservoir tank to insure a constant concentration. As the cloth passes through the frame, the water evaporates and some residual oils and chemicals are volatilized as the air temperature is maintained at 150-180°C. At the conclusion of a run the pad bath is dumped and the equipment washed down.

One tenter frame is used exclusively for heat setting of dyed and dryed goods. In this operation, the fabric is fed in an open form into the drying oven. As the cloth passes through the frame, with an air temperature at 175-200°C, significant amounts of residual oils and chemicals are volatilized and the fabric is partially plasticized to produce a particular texture or to stabilize the width dimension.

One tenter frame is used for either drying or heat setting as described above and also for frame scouring and dyeing. In this operation the padder is preceded by a scour bath and a rinsing chamber. Fabric is fed into the unit in a wide width form. The scour bath consists of a constant water volume tank into which scour chemicals are continuously fed. The rinsing chamber consists of a spray washer to remove the scour products. The padder bath may contain a solution of fluorescent dyes to optically brighten the fabric. Goods going this route are usually shipped as uniform fabric or sent to a commission printer. Another alternate route is to pre-frame the fabric before dyeing in the atmospheric becks by using only the scour bath, rinsing chamber, and frame.

The drying and heat setting operations are illustrated in Figure VI.

The air exhausts from the tenter frames contain significant amounts of pollutants in an aerosol form. At BRW, these exhausts are cleaned using electrostatic precipitators after air stream cooling. Water from the cooling step as well as equipment wash-down water is sent to the process sewer system. Therefore, a portion of the chemicals retained on the cloth from the dyeing process may eventually find their way to the sewer.

## Mechanical Processing

A number of mechanical processing steps are used at BRW to obtain a variety of textures.

In the velour product line the fabric is napped (torn ) and sheared (cut to a constant height) on the front face to give a soft, resillient pile.

If a suede texture is desired, the fabric is scoured, sueded (rubbed with sand paper) and then dyed.

A third route that is available is to emboss a pattern into the fabric after it is dyed and dryed by passing it under pressure through a set of pattern roles. For certain fabrics, heat is applied simultaneously with pressure, to partially placticize the fiber and give a "wet" or shiny appearance.

In all cases, mechanical finishing processes are dry except for the use of a small volume of cooling water for the machinery.

## PART B - 3 - MANUFACTURING OPERATIONS: DYE AND CHEMICAL USE

During the course of a production year, a textile firm may use several hundred different dyes and chemicals in the manufacturing processes. For BRW the total usually is in the range of 150-200 different dyes and chemicals, but a much smaller range accounts for the greatest usage.

For the dyes category, three dyes (all disperse) account for twenty-five percent of total use and 25 dyes account for fifty percent of total use. A total of over 100 dyes were used during the study year but the use of most of these was less than 1.0 percent of total use. Approximately 30 percent of the dyes used were of the acid class and accounted for 20 percent of the total use. Approximately 70 percent were of the disperse class and accounted for 80 percent of the total use.

Acid dyes are water soluble dyes which are used principally with nylon, acrylic, and wool fibers. The chromogen is usually an azo (-N=N-), anthroquinone (=C=O), or triarylmethane (=C=NH) structure with the auxochromes being $-NO_2$, $-SO_3H$, or -COOH. The anionic dyes attach to the cationic groups in the fiber. Quite often they contain a metal as part of the organic structure to make the dye more stable. At BRW, acid dyes are typically used at a water: fabric:dye weight ratio of 1:35 to 70:0.02 to 0.08 in atmospheric beck dyeing. Acetic acid is used to lower the dyebath pH to 4 to 5 in order to aid in exhaustion, and sodium sulfate may be used to decrease the rate at which the dye is attached.

Disperse dyes are water insoluble dyes which are used principally with acetate, polyester, nylon, and acrylic fibers. The chromogen is usually an azo or anthraquinone structure and the dyes have a neutral charge. The dyes are used in conjunction with a dispersing agent which holds the dye in suspension, and a carrier to aid the dye in penetrating the fiber. Disperse dye suspensions vary from 0.1 to 3 microns in size depending on the dye and the dye manufacturing process. The degree of solubility is very low with anthraquinone types being soluble only to several parts per million. Typically, from three to ten percent of the dye used in a bath may go into solution. At BRW, disperse dyes are typically used at a water:fabric:dye weight ratio of 1:5 to 10:0.04 to 0.08 in beam dyeing and the dye cycle is carried out at an elevated temperature to reduce the time required for migration and striking. Also at BRW, the dyes are applied in a pad bath on a continuous range for light shades.

Because of their high costs, the exhaustion rate (percent of dye removed from the dyebath solution) of dyes tend to be significant. However, the exhaustion rate is a function of competing dyestuffs, fiber type, auxillary chemicals, temperature, and cycle time. Therefore, it is difficult to predict how much of a certain dye is actually wasted to the sewer. A good example of this variation in exhaustion at BRW is Acid Green 25. In some baths it is the primary colorant and its exhaustion rate approaches 90 percent, but in other situations where it is used as a secondary colorant (e.g. to give a green tint to a black shade) its exhaustion rate may be as low as 50 percent.

For the chemical category, 8 chemicals account for 50 percent of total use and 33 chemicals account for 97 percent of total use. A total of approximately 100 chemicals were used during the year with an average use of one to three percent for the significant chemicals. These chemicals have a large variety of uses and represent a very broad range of inorganic and organic materials. However, they can be divided into the following general categories:

- Inorganic chemicals
- Organic acids
- Detergents
- Carriers
- Dyeing assistants
- Finishes
- Solvents
- Fixing chemicals
- Fluorescents

Inorganic chemicals account for approximately 15.0 percent of the total use. They are used prinicipally in the fabric preparation steps. It is probable that the greatest majority of these chemicals go to the sewer and are not retained on the fabric.

Organic acids account for approximately 7.6 percent of the total use. They are used primarily for pH control in the preparation and dyebath steps. Again, virtually all the chemical is estimated to go to the sewer.

Detergents account for approximately 13.8 percent of total use. They are primarily weak anionic or non-ionic surfactants, and are used in the scour baths to remove the small amount of dirt retained during knitting and warehousing and to remove lubricants or other residual materials associated with the yarn manufacturing. A high percentage of these chemicals is probably discharged to the sewer along with the contaminants they remove.

Carriers account for approximately 22.2 percent of total use. These chemicals are used as an auxillary to disperse dyes. Their functions are to (1) swell the fabric to allow the dye molecules to enter and (2) to coat the fibers in order to serve as the mechanism to allow transfer of the dye from the water suspension to the fiber by the preferential solubility of the dye in the carrier. The majority of a chemical in this category is probably discharged to the sewer but a portion is retained on the fabric and lost to the atmosphere during drying.

The broad classification of dyeing assistants account for 21.7 percent of total use and tend to be surfactants. These chemicals are used for dye suspension, leveling, penetration, fastness, and to aid in obtaining a finished fabric texture.

Finishes account for approximately 8.0 percent of the total use. The purpose of these chemicals is to impart a certain texture or repellent property to the fabric. For this reason their retention rate on the fabric is probably high.

Solvents account for approximataly 8.6 percent of the total use. In one case at BRW, a solvent is used in the scour bath to remove grease and oil from particularly dirty fabric. In the other case, a solvent is used to clean the padder rolls in the continuous range and finishing areas. This latter material contains a high concentration of an aromatic chemical. In both cases, virtually all of the material is discharged to the sewer.

Fixing chemicals account for approximately 2.1 percent of total use. The principle chemical is a surfactant and is used to insure fastness of the dye to the fiber.

Fluorescents account for approximately 1.0 percent of total use. These chemicals are fluorocarbon compounds used to whiten fabric in the uniform product line or to provide a background color for print patterns.

# SECTION V

# WASTEWATER CHARACTERIZATION

## PART A - ANALYTICAL AND SAMPLING METHODS

The methods of analyses and the sample preparation methods used during the study are presented in Appendix C of this report.

The following automatic sample points were established at the treatment plant for continuous monitoring wastewater characteristics:

- Equalized waste pump discharge
- Activated sludge clarifier overflow
- Alum coagulation clarifier overflow

Sampling stations at these locations consisted of finger pumps operated on a timed cycle (Sigmamotor model 7462). The pumps were operated for five minutes every fifteen minutes at a flow rate yielding about four liters every eight hours. Equal volumes from each shift bottle were then mixed to give a single daily composite. The tubing used for sampling was 1/4 inch (0.6 cm;I.D.) Tygon.

Several months into the study, a grab sampling station was established for the incoming municipal water used in production. These grab samples were obtained directly after the plant's water softeners.

Samples of combined sludge were grab samples taken at the inlet of the holding tank. Samples of the individual sludges were taken at the pump discharges.

Sampling of wastewater from individual production process was done by production personnel. The samples obtained were grab samples selected to give a representation of the overall characteristics of the discharge.

Periodic samples of receiving stream water above the BRW discharge were obtained. These were grab samples obtained by the use of wide mouth polyethylene jars. Sample points downstream

# TABLE IX

# SAMPLING AND ANALYSIS MATRIX

## SAMPLE POINTS AND LOCATIONS

| ANALYSES | EQUALIZED RAW WASTE | ACTIVATED SLUDGE CLARIFIER EFFLUENT | ALUM COAGULATION CLARIFIER EFFLUENT | AERATED LAGOON CONTENTS | COMBINED SLUDGE |
|---|---|---|---|---|---|
| FLOW | 1 | - | - | - | 1 |
| TDS | 1 | 1 | 1 | - | - |
| TSS | 1 | 1 | 1 | 2 | 2 |
| VSS | 1 | 1 | 1 | 2 | 2 |
| SVI | - | - | - | 2 | - |
| BOD | 1 | 1 | 1 | - | - |
| COD | 1 | 1 | 1 | - | - |
| TOC | 3 | 3 | 3 | - | - |
| TEMPERATURE | 1 | 1 | 1 | 2 | - |
| DO | 1 | 1 | 1 | 2 | - |
| PH | 1 | 1 | 1 | 2 | 4 |
| COLOR | 1 | 1 | 1 | - | - |
| $NH_3N$ | 1 | 1 | 1 | - | 4 |
| $OP_4$ | 1 | 1 | 1 | - | 4 |
| METALS | 3 | 3 | 3 | - | 4 |
| PHENOLICS | 3 | 3 | 3 | - | 4 |
| INORGANIC SALTS | 3 | 3 | 3 | - | 4 |

NOTES:

1. REGULAR ANALYSIS OF COMPOSITE SAMPLE
2. REGULAR ANALYSIS OF GRAB SAMPLE
3. MONTHLY ANALYSIS OF COMPOSITE SAMPLE
4. MONTHLY ANALYSIS OF GRAB SAMPLE

of the several dischargers were selected to allow for in-stream mixing and were at a point of turbulence in the stream.

Daily samples were analyzed for routine contaminants at the BRW Water Quality Laboratory in Bangor. Each month one set of daily samples was shipped to Pollution Control Science, Inc. in Dayton, Ohio, for analyses for heavy metals, salts, and particular organics. EPA recommended preservation techniques were used for these monthly samples.

The sample and analysis matrix used during the study is presented in Table IX.

A quality control check was made for metals analyses using split samples spiked with EPA standard solutions, and the results of this check were within acceptable tolerance limits.

Samples were always taken either in glass or polyethylene bottles. The cleaning of the sample bottles was dependent on their use, with bottles for routine analysis receiving only a wash with tap water and bottles for metals analysis receiving a double acid/distilled water wash. Distilled water in the BRW lab was prepared using a copper still. BOD dilution water was prepared in a five gallon carboy on a routine basis using the procedure in Standard Methods(15), and seed from the BRW activated sludge process. Reagent standards were prepared in the BRW laboratory in accordance with Standard Methods.

## PART B - SUMMARY OF WASTEWATER CHARACTERISTICS

Table X presents a summary of the equalized wastewater characteristics.

The median equalized flow value for the study period was determined to be 520,000 gallons per day. As illustrated by Figure VII, there was a significant variation in day-to-day and month-to-month flow. The standard deviation was found to be approximately 45 percent of the average.

The organic chemical concentration as measured by total BOD and COD values (that is, soluble plus insoluble) was determined to be significant. The relatively few soluble BOD and COD determinations that were made indicated that approximately 80 percent of the total values result from soluble material (that is, material passing a glass fiber filter). Several 20 day BOD determinations were made, and as the data in Figure VIII illustrates, $BOD_{20}$ for the equalized waste was found to be approximately twice the $BOD_5$.

The BOD and COD concentration values were found to be relatively stable with the standard deviation being approximately 25 percent of the average. However, the BOD and COD loading values were found to vary significantly with the standard deviation being approximately 50 percent of the average.

The suspended and dissolved solids concentrations were found not to be significantly high.

The nutrient (nitrogen and phosphorous) content of the wastewater was determined to be relatively high. Several analyses indicated that ammonia nitrogen and orthophosphate were the only significant forms of the major nutrients that were present.

Appreciable color was found to be present in the wastewater as a result of less than total exhaustion of disperse and acid dyes during production. Since the APHA color measurement method was used, the color concentrations determined were only approximate. However, since the pH and the hue of the BRW equalized water was found to be relatively constant, the use of the method was satisfactory to indicate variation in color concentration and color removal through the treatment system.

# TABLE X

## SUMMARY OF EQUALIZED WASTE CHARACTERISTICS

| CONTAMINANT | MEDIAN YEARLY VALUE | YEARLY STANDARD DEVIATION | LOW MONTHLY AVERAGE VALUE | HIGH MONTHLY AVERAGE VALUE |
|---|---|---|---|---|
| FLOW (MGD) | 0.520 | 0.204 | 0.200 | 0.646 |
| TEMPERATURE (°C) | 34.6 | 3.5 | 25.3 | 36.0 |
| PH | 6.7 | 0.4 | 6.1 | 6.9 |
| COLOR (APHA) | 1032 | 340 | 806 | 1,906 |
| DISSOLVED OXYGEN (MG/L) | 1.3 | 1.6 | 0.2 | 3.9 |
| BOD (MG/L) | 448 | 118 | 386 | 555 |
| COD (MG/L) | 1,554 | 351 | 1,158 | 1,985 |
| SUSPENDED SOLIDS (MG/L) | 174 | 251 | 46 | 395 |
| VOLATILE SUSPENDED SOLIDS (MG/L) | 140 | 185 | 90 | 288 |
| DISSOLVED SOLIDS (MG/L) | 712 | 153 | 542 | 930 |
| AMMONIA NITROGEN (MG/L AS $NH_3$-N) | 15.0 | 7.3 | 11.1 | 23.7 |
| ORTHOPHOSPHATE (MG/L AS $PO_4$) | 59.4 | 14.9 | 43.2 | 70.5 |
| ALUMINUM (MG/L) | 8.5 | - | 0.2 | 31.4 |
| CALCIUM (MG/L)[a] | 2.02 | - | 0.004 | 10.0 |
| CHROMIUM (MG/L)[a] | 0.58 | - | 0.11 | 1.21 |
| HEXAVALENT CHROMIUM (MG/L)[a] | 0.05 | - | 0.25 | 0.19 |
| COPPER (MG/L) | 0.03 | - | 0.005 | 0.50 |
| IRON (MG/L) | 0.41 | - | 0.05 | 0.70 |
| LEAD (MG/L)[a] | 0.025 | - | 0.006 | 0.045 |
| MAGNESIUM (MG/L)[a] | 2.40 | - | 0.32 | 10.0 |
| NICKEL (MG/L)[a] | 0.01 | - | 0.005 | 0.08 |
| POTASSIUM (MG/L)[a] | 4.2 | - | 1.97 | 6.68 |
| SODIUM (MG/L)[a] | 155 | - | 78 | 330 |
| ZINC (MG/L) | 0.13 | - | 0.08 | 1.96 |
| MERCURY (MG/L)[a] | 0.0016 | - | 0.0001 | 0.005 |
| PHENOLICS (MG/L) | 0.10 | - | 0.053 | 0.250 |
| TOC (MG/L) | 360 | - | 300 | 480 |
| CHLORIDE (MG/L)[a] | 43 | - | 36 | 51 |
| SULFATE (MG/L)[a] | 154 | - | 22 | 425 |
| ALKALINITY | 103 | - | 75 | 186 |
| DETERGENT | 15.4 | - | 5.4 | 35.0 |

[a] AVERAGE VALUE NOT MEDIAN VALUE

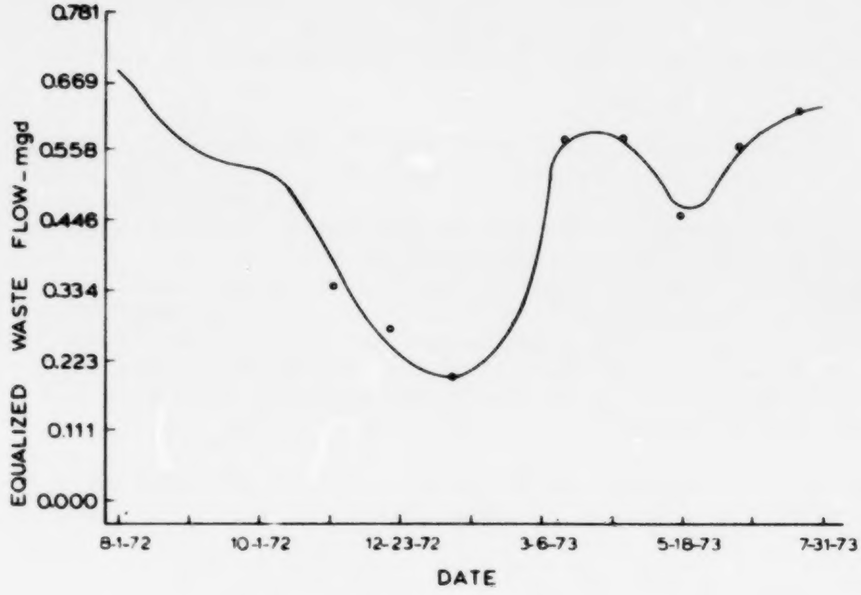


FIGURE VII. Chronological plot of daily equalized waste flow

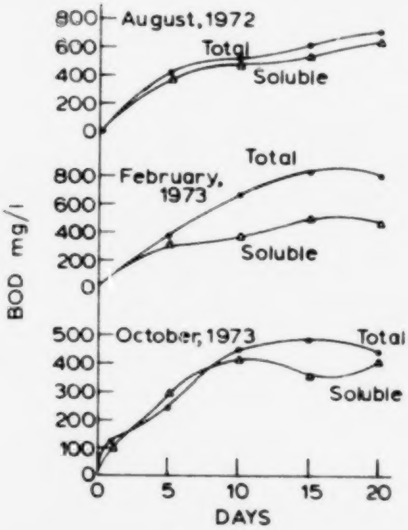


FIGURE VIII. Graph of twenty day BOD data for equalized raw waste

Figure IX indicates the affect of pH on the APHA color of the BRW wastewater.

Several spectrophotometric plots were made of the equalized waste and representative data is presented in Figure X.

A number of metals were present in the wastewater in significant concentrations. The aluminum concentration was found to be approximately 50 percent soluble and was estimated to result primarily from the presence of recycled alum sludge as described in Section XII. However, some aluminum appears to have been added during the production operation. The zinc concentration was 65 percent soluble and was due solely to the presence of zinc in the municipal water purchased for production use.

The chromium concentration was 80 percent soluble and resulted primarily from the dyes used in manufacturng, primarily the acid class of dyes. The iron concentration was 80 percent soluble, and the mill piping system was thought to be the primary source of this contaminant.

Only a trace concentration of phenol was found in the wastewater. The source of the contaminant was not investigated.

The pH of the equalized wastewater was constant and slightly acidic. The average temperature was 35°C, and the average dissolved oxygen content was 1.3 mg/l.

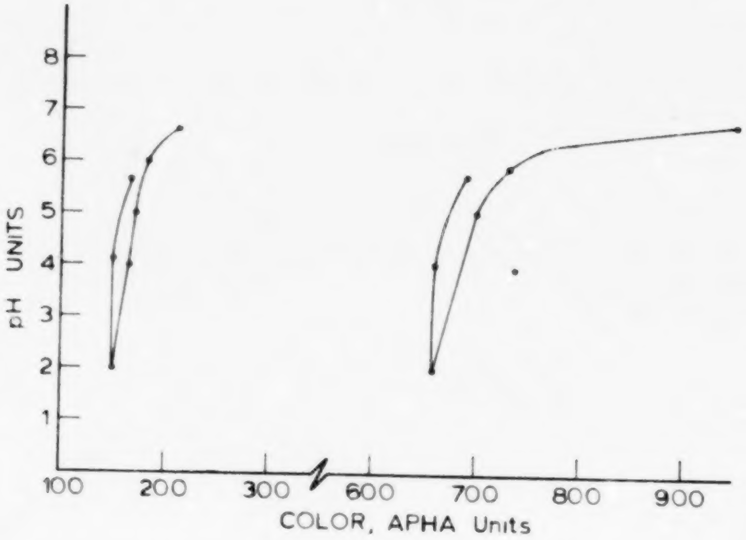


FIGURE IX. Wastewater color as a function of pH

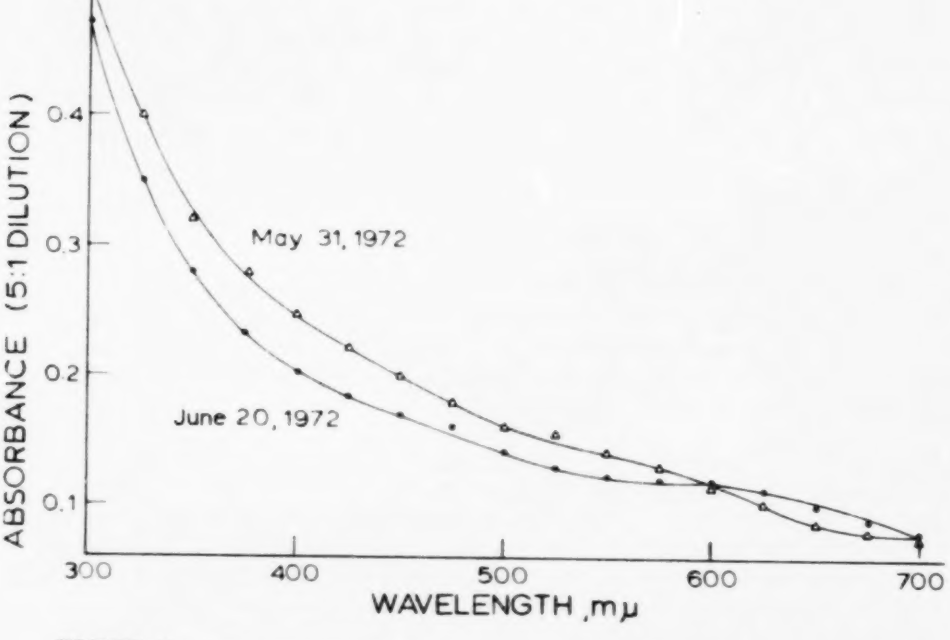


FIGURE X. Spectrophotometric curves for equalized raw waste

# SECTION VI

# GENERAL DESCRIPTION OF THE TREATMENT SYSTEM

The wastewater treatment facility at BRW consists of the following unit operations:

- Heat reclamation
- Equalization
- Activated sludge treatment
- Chlorination
- Sludge dewatering by centrifugation

A layout of the facility is presented in Figure XI and the process flow is presented in Figure XII.

In reviewing the system it is important to realize that significant changes and additions were made to the initial facility during the course of the project in order to improve treatment levels. These modifications are discussed in this report, and the drawings of the system indicate the facility as it existed at the completion of the data collection phase.

## HEAT RECLAMATION

The raw waste at BRW is collected in a common wastewater sump in Mills One and Two. The wastewater temperature ranges from 38°C to 50°C, and is a candidate for heat recovery. During the study, a shell and u-tube exchanger was used to preheat water for the hot water feed system in Mill Number Two.

In this exchanger, wastewater flowed on the tube side and to prevent plugging, the wastewater was screened twice before being pumped to the exchanger. The first screening consisted of a series of three screens mounted in the trench system at several locations. These screens were successively coarse to fine mesh (1.27, 0.64, 0.32 centimeter openings), and were manually cleaned. The second screening consisted of a medium screen (0.64 centimeter openings) concentric to and running the full length of the vertical suction pipe of each raw waste pump.

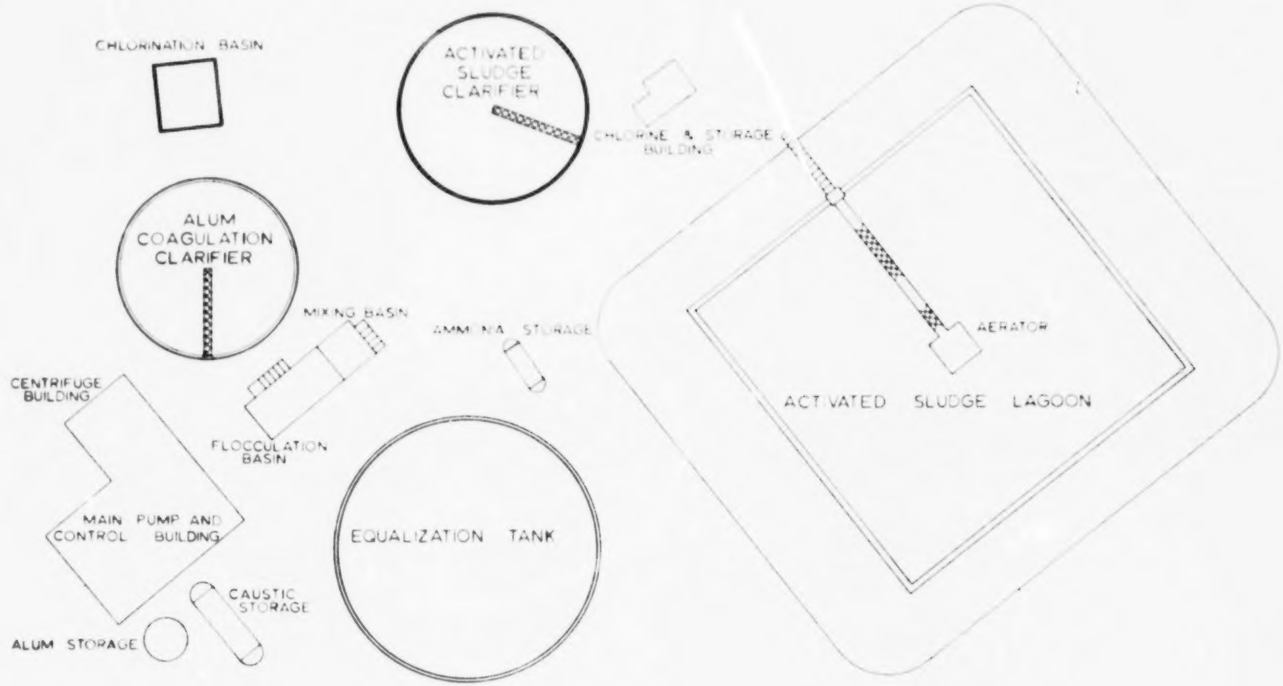

CHLORINATION BASIN
ACTIVATED SLUDGE CLARIFIER
CHLORINE & STORAGE BUILDING
ALUM COAGULATION CLARIFIER
MIXING BASIN
AMMONIA STORAGE
AERATOR
CENTRIFUGE BUILDING
ACTIVATED SLUDGE LAGOON
FLOCCULATION BASIN
MAIN PUMP AND CONTROL BUILDING
EQUALIZATION TANK
CAUSTIC STORAGE
ALUM STORAGE

FIGURE XI. Site plan - wastewater treatment plant

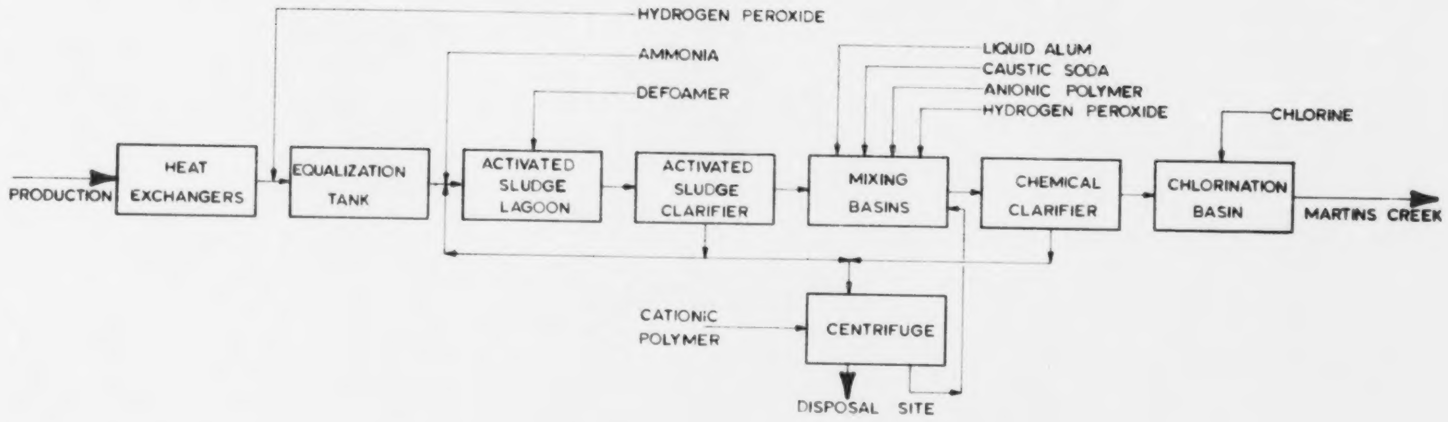

HYDROGEN PEROXIDE
AMMONIA
DEFOAMER
LIQUID ALUM
CAUSTIC SODA
ANIONIC POLYMER
HYDROGEN PEROXIDE
CHLORINE
PRODUCTION
HEAT EXCHANGERS
EQUALIZATION TANK
ACTIVATED SLUDGE LAGOON
ACTIVATED SLUDGE CLARIFIER
MIXING BASINS
CHEMICAL CLARIFIER
CHLORINATION BASIN
MARTINS CREEK
CATIONIC POLYMER
CENTRIFUGE
DISPOSAL SITE

FIGURE XII. Wastewater treatment plant process flow sheet

## EQUALIZATION

The production week at BRW may vary from five and one third days to seven days during normal production periods. Also there are a number of three day holiday shutdowns and two, ten day vacation period shutdowns during the course of a production year. Because wastewater is required for the activated sludge system on a continuous basis, an equalization tank was provided for storage and for contaminant equalization. This tank was an open top steel vessel, 70 feet (21.3 meters) in diameter and 36 feet (11.0 meters) high with a nominal capacity of one million gallons (3785 cubic meters).

Influent to the tank was pumped from the wastewater collection sumps in Mills One and Two through a discharge header running the diameter of the vessel. A circulation pump was provided to withdraw waste from the tank and pump it back through the header with the incoming raw waste.

No other mixing was provided in the tank, and as a result some sedimentation did occur. The combination of this sedimentation, the ready biodegradability of a portion of the waste, and the low dissolved oxygen content of the raw waste resulted in the generation of septic odors. A hydrogen peroxide feed system to the equalization tank was installed late in the study and successfully abated the problem.

## ACTIVATED SLUDGE TREATMENT

The activated sludge process consisted primarily of an aerated lagoon and a clarifier. Equalized waste was pumped to the lagoon through a flow control instrumentation loop.

The aerated lagoon was a lined, earthen basin with a capacity of 336,000 gallons (1272 cubic meters). Aeration and mixing was proved by a single, 125 horsepower (93 kilowatts), platform mounted aerator of the vaned, inverted cone type. Capacity of this unit was 415 pounds (188 kilograms) of oxygen per hour at standard conditions (tap water at 20°C with a dissolved oxygen level of 0.0 mg/l and an $\alpha$ and $\beta$ of 1.0 each) or 136 pounds (62 kilograms) of oxygen per hour at design conditions ($\alpha = 0.51$, $\beta = 0.9$, D.O. = 2.0 mg/l, and temperature = 25°C).

The clarifier was an above grade steel vessel 50 feet (15.2 meters) in diameter with a side water depth of 8 feet (2.4 meters) and contained a rotating, suction type sludge collection mechanism with a peripheral discharge weir. Settled sludge in the clarifier was returned back to the aeration basin on a continuous basis, but was limited to a rate of 150-200 gallons per minute (0.57-0.76 cubic meters per minute).

Return sludge and equalized raw waste were pumped to the same header which discharged the mixture in the lagoon at the bottom directly under the aerator.

Initial studies on the waste indicated possible nutrient deficiencies, and therefore provisions were made for adding phosphoric acid and anhydrous ammonia (industrial grade) to the equalized waste pump discharge. The phosphorous content of the wastewater was found to be adequate for the activated sludge system and the phosphoric acid equipment was removed before the start of the project. Ammonia was added, however, to determine if supplemental nitrogen was required for biological oxidation.

Because foaming in the aeration basin was expected, provisions were made to add a chemical defoamer directly to the equalized waste pump discharge. This did not prove to be effective and the addition point was moved to the lagoon surface. While this was satisfactory for warm weather operation, winter operation necessitated moving the feed equipment indoors and injecting the defoamer into a dilution water line for transport to the lagoon at a 0.1 percent concentration. Also a block foam baffle was constructed around the perimeter of the lagoon after start-up to prevent wash-out of solids due to excessive foaming.

## ALUM COAGULATION TREATMENT

The alum coagulation process consisted primarily of mixing and flocculation basins and a clarifier.

Initially, liquid alum (commercial grade, 17% $AL_2O_3$) was added to the discharge pipe of the activated sludge clarifier without mixing. This arrangement did not prove totally satisfactory, and as a result, a rapid mix basin and a flocculation basin were put into service in May, 1973. The mixing facility consisted of a 1,500 gallon (5.6 cubic meter) concrete basin with two, 5 horsepower (3.7 kilowatt), turbine mixers (mixing speeds of 168 and 84 rpm are possible using interchangeable gears). The flocculation facility consisted of a 15,000 gallon (56.8 cubic meter) concrete basin with two, 1.5 horsepower (1.1 kilowat), vertical paddle turbine mixers (mixing speeds of 12 to 37 rpm are possible by variable speed drives).

Initially caustic soda (50% strength) was added to the clarifier effluent for final pH control, but this arrangement was changed in May, 1973, to caustic soda addition at the rapid mix basin simultaneously with the alum.

Polymer addition was not begun until May, 1973 when a polymer feed system was put into service. A dry anionic polymer (Magnifloc 837A) is mixed to a 0.2 percent concentration in a 300-gallon (1.1 cubic meter) tank and then pumped into a water line for dilution and transport to the flocculation basin at a 0.05 percent concentration.

The alum sludge is settled out in a 44 foot (13.4 meter) diameter, 12 foot (3.6 meter) side water depth, below grade concrete clarifier. Sludge was collected by a plow type mechanism and the supernatant overflowed a peripheral weir. The clarifier mechanism included a 14 (4.3 meter) foot flocculation section with a vertical paddle mixer but provided no solids circulation.

Collected sludge was removed periodically from the clarifier and further processed.

During the project, a problem developed from septic odors in the final clarifier due to oxygen depletion in the sludge blanket. As a solution, a hydrogen peroxide feed system was installed to inject the chemical into the flocculation basin discharge. Peroxide addition eliminated the septicity problem with no peroxide carryover in the final effluent.

## CHLORINATION

Overflow from the alum coagulation clarifier discharged into an 8000 gallon (30.3 cubic meter) below grade concrete chlorination basin. Mixing in the basin was provided by around-the-end baffles. A side stream of effluent was pumped back to the chlorine building, gaseous chlorine injected from 150 pound (68 kilograms) cylinders, and the mixture returned to the head of the basin. Overflow from the basin was discharged down a 25 foot (7.6 meter) long rock spillway to a storm sewer for eventual discharge into Martins Creek, a tributary of the Delaware River.

## SLUDGE HANDLING FACILITIES

Originally, the excess activated sludge and the chemical (alum) sludge from the treatment facility were combined before further processing.

The combined sludge was sent to an open top, steel storage tank and then processed on a precoat vacuum filter. The filter had a surface area of 200 square feet (18.6 square meters), used diatamaceous earth on cotton cloth as the filter base, and had a rated capacity of 10 gallons per minute (0.03 cubic meter per minute) with a one percent sludge. This filter had been part of the first treatment facility at DRW, and eventually proved to be inadequate to handle the sludge load.

Filtrate from the unit was discharged back to the wastewater sump in Mill Number One. The sludge cake containing the sludge and pre-coat was discharged into a dump truck for transportation to a landfill for disposal using conventional practice. Overflow from the storage tank was discharged back to the Mill Number One sump.

Late in the study, operation of the filter was discontinued, and the sludge slurry was hauled directly from the storage tank to ocean disposal. During this period of time evaluations were made of sludge dewatering on a horizontal scroll centrifuge, and in March, 1974, a centrifuge of this type was put into service. The unit was a Sharples P-3400 capable of dewatering up to 35 gallons per minute (0.15 cubic feet per minute) of a two percent sludge. A highly charged cationic polymer (Magnifloc 335) was applied at a concentration of five percent to aid cake dryness and solids recover. The alum sludge and excess activated sludge were normally dewatered separately, although, at times, they were successfully combined and dewatered.

Centrate from the centrifuge was discharged back to the flocculation basin. The sludge cake was discharged into a screw conveyor and transported to a closed top dumpster. This dumpster was removed by a contract hauler for eventual disposal of the sludge cake in the ocean outside the 116 mile (186.7 kilometer) limit (in late 1974 the disposal site is expected to change to a permitted landfill for burial using a lime encapsulation method).

A summary of major treatment system process parameters is presented in Table XI.

# TABLE XI

## SUMMARY OF MAJOR TREATMENT SYSTEM PROCESS PARAMETERS

| | |
|---|---|
| COLLECTION SUMP CAPACITY | |
| MILL NUMBER ONE | 11,300 GALLONS (42.8 CUBIC METERS) |
| MILL NUMBER TWO | 3,000 GALLONS (11.4 CUBIC METERS) |
| MILL NUMBER TWO HEAT EXCHANGER | |
| WASTEWATER INLET/OUTLET TEMPERATURE | 100° F/80° F (38°C/27°C) |
| CAPACITY | $1 \times 10^6$ BTU/HR. (290 KILOWATTS) |
| EQUALIZATION TANK | |
| DIAMETER | 70 FEET (21.4 METERS) |
| HEIGHT | 36 FEET (11.0 METERS) |
| WORKING HEIGHT | 34.5 FEET (10.5 METERS) |
| WORKING VOLUME | 990,000 GALLONS (3740 CUBIC METERS) |
| CIRCULATION PUMP CAPACITY | 500 GALLONS/MINUTE (31.5 LITER/SEC) |
| HYDROGEN PEROXIDE FEED CAPACITY | 1 GALLON/HOUR (1.05 ML/SEC) |
| AERATION BASIN | |
| BOTTOM DIMENSION | 47 FEET X 47 FEET (14.3M X 14.3M) |
| SIDE SLOPE | 2:1 |
| WATER DEPTH | 10 FEET (3.048 METERS) |
| CAPACITY | 336,000 GALLONS (1270 CUBIC METERS) |
| ANHYDROUS AMMONIA FEED CAPACITY | 2 POUNDS/HOUR (0.91 KILOGRAM/HR) |
| DEFOAMER FEED CAPACITY | 2 GALLONS/HOUR (2.1 LITERS/SEC) |
| AERATOR | |
| HORSEPOWER | 125 HP (93 KILOWATTS) |
| HORSEPOWER: VOLUME RATIO | 0.37HP/1000 GALLONS (74 WATTS/CUBIC METER) |
| AERATION CAPACITY | |
| TEMP = 20°C $\alpha$ = 1 $\beta$ = 1 D.O. = 0 MG/L | 415 POUNDS $O_2$/HOUR (188 KG/HR.) |
| TEMP = 25°C $\alpha$ = 0.75 $\beta$ = 0.9 D.O. = 2 MG/L | 136 POUNDS $O_2$/HOUR (61.6 KG/HR.) |
| AERATION CAPACITY:VOLUME RATIO | |
| TEMP 20°C $\alpha$ = 1 $\beta$ = 1 D.O. = 0 MG/L | 1.24 POUNDS $O_2$/HOUR/ 1000 GALLONS (149G/HR/CUBIC METER) |
| TEMP 25°C $\alpha$ = 0.75 $\beta$ = 0.9 D.O. = 2 MG/L | 0.40 POUNDS $O_2$/HOUR/ 1000 GALLONS (48 G/HR/ CUBIC METER |

## TABLE XI (CON'T)

ACTIVATED SLUDGE CLARIFIER

| | |
|---|---|
| DIAMETER | 50 FEET (15.2 METERS) |
| SIDE WATER DEPTH | 8 FEET (2.44 METERS) |
| BOTTOM SLOPE | 1/4 INCH PER FOOT (0.25 MM/CM) |
| SURFACE AREA | 1960 SQUARE FEET (182 SQUARE METERS) |
| CAPACITY | 117,500 GALLONS (445 CUBIC METERS) |
| RETURN SLUDGE RATE | 200-250 GALLONS/MINUTE CONTINUOUS (12.6 - 15.8 L/SEC.) |

RAPID MIX BASIN

| | |
|---|---|
| CAPACITY | 1500 GALLONS (56.7 CUBIC METERS) |
| NUMBER OF MIXERS | 2 |
| MIXER HORSEPOWER | 5 HP EACH (3.7 KILOWATTS) |
| WATER DEPTH | 5 FEET (1.52 METERS) |
| HORSEPOWER: VOLUME | 6.67 HP/1000 GALLONS (1.3 KILOWATTS/CUBIC METER) |
| SPEED RANGE | 84 OR 168 RPM |
| ALUM FEED CAPACITY | 18 GALLONS/HOUR (18.9 ML/SEC.) |
| CAUSTIC SODA FEED CAPACITY | 6 GALLONS/HOUR (6.3 ML/SEC.) |

FLOCCULATION BASIN

| | |
|---|---|
| CAPACITY | 15,000 GALLONS (56.5 CUBIC METERS) |
| NUMBER OF MIXERS | 2 |
| MIXER HORSEPOWER | 1.5 HP EACH (1.1 KILOWATTS) |
| WATER DEPTH | 12 FEET (3.7 METERS) |
| HORSEPOWER: VOLUME | 0.20 HP/1000 GALLONS (40 WATTS/CUBIC METER) |
| SPEED RANGE | 12 TO 37 RPM |
| POLYMER FEED CAPACITY | 50 GALLONS/HOUR (52.6 ML/SEC.) |
| HYDROGEN PEROXIDE FEED CAPACITY | 1 GALLON/HOUR (1.05 ML/SEC.) |

ALUM COAGULATION CLARIFIER

| | |
|---|---|
| DIAMETER | 44 FEET (13.4 METERS) |
| SIDE WATER DEPTH | 12 FEET 9 INCHES (3.9 METERS) |
| BOTTOM SLOPE | 1/2 INCH PER FOOT (0.4 MM/CM) |
| SURFACE AREA | 1520 SQUARE FEET (141 SQUARE METERS) |
| CAPACITY | 145,000 GALLONS (550 CUBIC METERS) |
| SLUDGE WITHDRAWAL RATE | 75 GALLONS/MINUTE (4.6 L/SEC)<br>0-60 MINUTES/HOUR |

CHLORINATION BASIN

| | |
|---|---|
| CAPACITY | 8000 GALLONS (30.2 CUBIC METERS) |
| WATER DEPTH | 5 FEET (1.52 METERS) |
| CHLORINATION CAPACITY | 25 MG/L |
| CONTACT TIME | 20 MINUTES |

## TABLE XI (CONT'D)

| | |
|---|---|
| VACUUM FILTER | |
| STORAGE TANK CAPACITY | 75,000 GALLON (284 CUBIC METERS) |
| FILTER SURFACE AREA | 200 SQUARE FEET (18.6 SQUARE METERS) |
| MAXIMUM FEED RATE | 10 GALLONS/MINUTE (0.63 L/SEC) |
| AVERAGE FEED CONCENTRATION | 1.0 PERCENT |
| SOLIDS CAPACITY | 50 POUNDS DRY SOLIDS/ HOUR (23 KG/HR) |
| FILTER CAKE LIFE | 2-3 DAYS |
| PRE-COAT TIME | 8-16 HOURS |
| PRE-COAT USAGE | 1,000 POUNDS/COAT (454 KG) |
| CENTRIFUGE | |
| MAXIMUM FEED RATE | 40 GALLONS/MINUTE (2.5 L/SEC.) |
| AVERAGE FEED CONCENTRATION | 2.0 PERCENT |
| BOWL SPEED | 3,000 RPM |
| CONVEYOR DIFFERENTIAL | 10-20 RPM |
| POLYMER DOSE | 5-15 POUNDS/TON DRY SOLIDS (2.5 - 7.5 KG) |
| SOLIDS CAPACITY | 400 POUNDS DRY SOLIDS/HOUR (182 KG/HR) |

# SECTION VII

# PRE-TREATMENT STEPS

## PART A - WASTE COLLECTION

The raw wastewater from the batch manufacturing operations was collected in a single sump in each mill. Table XII and presents an analysis of discharges from the individual production machinery into the Mill One sump. For the single day analyzed, there was a total calculated discharge of 425,180 gallons (1609 cubic meters), a peak flow of 36,690 gallons (139 cubic meters) per hour or 8.6 percent of the total, a median flow of 17,000 gallons (64 cubic meters) per hour, and a standard deviation of 11,500 gallons per hour. Instantaneous flows into the sump of as high as 2500 gallons per minute (9.5 cubic meters per minute) were possible when the large beam dyers were being dumped.

The trench screens were effective in removing a variety of trash that entered the trench system, and these screens were manually cleaned once each day. During the course of a year however, solid matter did pass through the screens and settle out in the sump necessitating an annual cleaning.

# TABLE XII

## ANALYSIS OF BATCH
## WASTEWATER DISCHARGES
## FROM THE MILL ONE DYEHOUSE

| TIME | TOTAL GALLONS DISCHARGED | PERCENT OF TOTAL | AVERAGE GALLONS PER MINUTE |
|---|---|---|---|
| AM | | | |
| 7-8 | 0 | 0.00 | 0 |
| 8-9 | 2,120 | 0.50 | 36 |
| 9-10 | 11,540 | 2.71 | 192 |
| 10-11 | 10,600 | 2.49 | 177 |
| 11-12 | 12,800 | 3.00 | 214 |
| PM | | | |
| 12-1 | 30,720 | 7.22 | 512 |
| 1-2 | 2,170 | 4.97 | 353 |
| 2-3 | 26,750 | 6.29 | 445 |
| 3-4 | 11,540 | 2.71 | 192 |
| 4-5 | 25,680 | 6.03 | 428 |
| 5-6 | 14,340 | 3.40 | 239 |
| 6-7 | 35,700 | 8.39 | 585 |
| 7-8 | 36,690 | 8.62 | 612 |
| 8-9 | 25,850 | 6.01 | 431 |
| 9-10 | 18,500 | 4.34 | 308 |
| 10-11 | 25,450 | 5.98 | 424 |
| 11-12 | 11,350 | 2.67 | 189 |
| AM | | | |
| 12-1 | 19,500 | 4.58 | 325 |
| 1-2 | 15,770 | 3.70 | 263 |
| 2-3 | 20,400 | 4.79 | 340 |
| 3-4 | 11,700 | 2.75 | 195 |
| 4-5 | 15,000 | 3.52 | 250 |
| 5-6 | 17,130 | 4.02 | 286 |
| 6-7 | 4,880 | 1.15 | 81 |
| TOTAL | 425,180 | 100.00 | - |
| MEDIAN | 17,000 | - | 258 |

NOTE: 100 GALLONS EQUALS 0.3785 CUBIC METERS

## PART B - HEAT RECLAMATION AND EQUALIZATION

### Heat Reclamation

The shell and u-tube exchanger in Mill Two was able to reclaim approximately one million BTU (0.25 million kilocalories) per hour for use in pre-heating feed to the hot water system.

### Equalization

The principle use of the equalization tank was for water storage to insure relatively constant flow to the treatment processes during low production periods or Mill shutdowns. The wastewater tended to be self-equalizing in regard to contaminant concentration despite the wide variations that were anticipated after examining the characteristics of the various baths that are part of a production cycle. Apparently, the random nature of the discharges from the 35 available dyeing units over a 24 hour period results in a self-equalizing affect. Table XIII presents the COD of the equalized waste over a 24 hour period, and the data illustrates the relative stability of the contaminant concentration with a one day equalization tank retention time.

The raw waste pumped to the equalization tank contained a low concentration (1.0 mg/l) of dissolved oxygen. At times, a significant level of solids was present in the waste which settled out in the relatively quiescent conditions of the tank. This situation was particularly acute when the vacuum filter system was not operating and there was an appreciable recirculation of solids from the sludge storage tank. The net result of these conditions was a depletion of available oxygen and the development of an anaerobic environment with consequent septic odors.

To overcome this condition, hydrogen peroxide addition to the raw waste was begun in mid-1973. It was determined that a dosage rate of 15-25 mg/l of hydrogen peroxide in the raw waste flow would be satisfactory to maintain an aerobic environment and yield an equalized waste dissolved oxygen level of at least 2.0 mg/l in the tank discharge.

In the late 1973, the tank was drained and cleaned after being in service since late 1971, and as evidence of the lack of mixing, approximately two feet of accumulated sludge was removed from the tank bottom.

# TABLE XIII

## ANALYSIS OF CONTAMINANT EQUALIZATION

| HOUR | COD (MG/L) |
|---|---|
| 0 | 1249 |
| 2 | 1218 |
| 4 | 1222 |
| 6 | 1284 |
| 8 | 1238 |
| 10 | 1270 |
| 12 | 1249 |
| 14 | 1168 |
| 16 | 1189 |
| 18 | 1157 |
| 20 | 1083 |
| 22 | 1150 |

| | |
|---|---|
| MEDIAN: | 1215 MG/L |
| STANDARD DEVIATION: | 60 MG/L |
| AVERAGE WASTEWATER VOLUME IN TANK: | 772,000 GALLONS (2922 CUBIC METERS) |
| AVERAGE RAW FLOW TO TANK: | 674,000 GALLONS (2551 CUBIC METERS) |
| AVERAGE EQUALIZED FLOW FROM TANK: | 792,000 GALLONS (2998 CUBIC METERS) |

# SECTION VIII

# ACTIVATED SLUDGE SYSTEM PERFORMANCE

## PART A - EFFLUENT CHARACTERISTICS

Table XIV presents a summary of the activated sludge effluent characteristics. Table XV presents a summary of the percentage removals for the process, calculated from the influent and effluent median values. The first column of this table indicates the removal based on a statistical analysis of all the data collected during the study. However, it was the author's opinion that this data is not truly representative of the process performance because of the number of mechanical problems encountered during the study as discussed in Section XVI of this report. Therefore, the second and third columns of Table XV present the percentage removals and effluent concentrations resulting from an analysis of the data during periods free of unusual problems. This latter data is intended to indicate the expected median performance levels (but not necessarily the best performance levels) for a well designed and operated facility.

The BOD removal through the process was determined to be 73 percent for the total data analysis and 78 percent for the selective data analysis, indicating that a significant portion of the waste loading consists of bio-degradable organic material. This removal rate is somewhat less than obtained by other activated sludge systems treating textile wastes, as reported in the general literature. The probable reason for this is the significant carryover of biological solids from the clarifier. While the poor influent design of the clarifier was primarily the cause of this situation, an examination of the data indicates that even with better designed inlet conditions, there would still be a net increase in suspended solids across the process. The available soluble BOD data across the system indicated an 88 percent removal.

# TABLE XIV

## SUMMARY OF ACTIVATED SLUDGE EFFLUENT CHARACTERISTICS

| CONTAMINANT | MEDIAN YEARLY VALUE | YEARLY STANDARD DEVIATION | LOW MONTHLY AVERAGE VALUE | HIGH MONTHLY AVERAGE VALUE |
|---|---|---|---|---|
| TEMPERATURE (°C) | 25.1 | 6.0 | 9.3 | 29.3 |
| PH | 6.8 | 0.2 | 6.4 | 6.8 |
| COLOR (APHA) | 804 | 348 | 381 | 1,441 |
| DISSOLVED OXYGEN (MG/L) | 1.7 | 2.7 | 1.0 | 5.3 |
| BOD (MG/L) | 122 | 83 | 34 | 225 |
| COD (MG/L) | 1,056 | 359 | 509 | 1,508 |
| SUSPENDED SOLIDS (MG/L) | 368 | 236 | 103 | 539 |
| VOLATILE SUSPENDED SOLIDS (MG/L) | 316 | 200 | 52 | 435 |
| DISSOLVED SOLIDS | 619 | 170 | 408 | 790 |
| AMMONIA NITROGEN (MG/L AS $NH_3H$) | 4.8 | 3.4 | 3.8 | 11.4 |
| ORTHOPHOSPHATE (MG/L AS $PO_4$) | 65.1 | 65.1 | 40.0 | 82.0 |
| ALUMINUM (MG/L)[a] | 12.5 | - | 0.69 | 23.4 |
| CALCIUM (MG/L) | 1.48 | - | 1.06 | 2.22 |
| CHROMIUM (MG/L) | 0.36 | - | N.D. | 0.05 |
| HEXAVALENT CHROMIUM[a] (MG/L) | N.D. | - | - | - |
| COPPER (MG/L) | 0.03 | - | N.D. | 0.05 |
| IRON (MG/L) | 0.57 | - | 0.14 | 0.86 |
| LEAD (MG/L)[a] | 0.028 | - | N.D. | 0.070 |
| MAGNESIUM (MG/L)[a] | 1.57 | - | 0.36 | 4.00 |
| NICKEL (MG/L)[a] | 0.01 | - | N.D. | 0.10 |
| POTASSIUM (MG/L)[a] | 2.82 | - | 1.40 | 3.96 |
| SODIUM (MG/L)[a] | 154 | - | 76 | 352 |
| ZINC (MG/L) | 0.22 | - | 0.02 | 0.49 |
| MERCURY (MG/L)[a] | 0.0018 | - | 0.0001 | 0.0040 |
| PHENOLICS (MG/L) | 0.03 | - | N.D. | 0.08 |
| TOC (MG/L) | 200 | - | 64 | 378 |
| CHLORIDE (MG/L)[a] | 46 | - | 40 | 56 |
| SULFATE (MG/L)[a] | 144 | - | 24 | 330 |
| ALKALINITY (MG/L) | 66 | - | 50 | 94 |

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[a] Average Values

## TABLE XV

## SUMMARY OF PERCENTAGE REMOVALS IN ACTIVATED SLUDGE

| CONTAMINANT | REMOVAL BASED ON TOTAL DATA ANALYSIS (PERCENT) | REMOVAL BASED ON SELECTIVE DATA ANALYSIS (PERCENT) | EFFLUENT CONCENTRATION BASED ON SELECTIVE DATA ANALYSIS (MG/L) |
|---|---|---|---|
| BOD | 73 | 78 | 96 |
| COD | 32 | 42 | 901 |
| COLOR | 22 | 30 | 722 APHA |
| SUSPENDED SOLIDS | (111) | (100) | 348 |
| DISSOLVED SOLIDS | 13 | 13 | 619 |
| AMMONIA NITROGEN | 68 | 73 | 4.0 |
| ORTHOPHOSPHATE | (10) | 0 | 59.4 |
| ALUMINUM | (47) | 0 | 8.5 |
| CALCIUM | 27 | 27 | 1.48 |
| CHROMIUM | 38 | 38 | 0.36 |
| HEXAVALENT CHROMIUM | 100 | 100 | N.D. |
| COPPER | 0 | 0 | 0.03 |
| IRON | (28) | (28) | 0.57 |
| LEAD | (12) | (12) | 0.028 |
| MAGNESIUM | 34 | 34 | 1.57 |
| NICKEL | 0 | 0 | 0.01 |
| POTASSIUM | 33 | 33 | 2.82 |
| SODIUM | 1 | 1 | 154 |
| ZINC | (69) | (69) | 0.22 |
| MERCURY | (12) | (12) | 0.0018 |
| PHENOLICS | 73 | 73 | 0.03 |
| TOC | 45 | 45 | 200 |
| CHLORIDE | (7) | (7) | 46 |
| SULFATE | 9 | 9 | 144 |
| ALKALINITY | 36 | 36 | 66 |

The COD removal through the process was determined to be 32 percent for the total data analysis and 42 percent for the selective data analysis. This lower removal rate for COD compared to BOD indicates a significant portion of the waste loading consists of non-biodegradable organic material. The COD removal percentage is also influenced by the high suspended solids levels in the effluent, but to a lesser degree than the BOD values. In comparing soluble COD data across the system, 45 percent removal was indicated.

Color removal across the process was 22 percent for the total data analysis and 30 percent for the selective data analysis. The mechanism for this removal may be primarily by flocculation or adsorption of dyes by the microorganisms since the available literature indicates little degradation of most dyes by biological systems(2). In addition to adsorption, some precipitation of disperse dyes could have occurred if the associated dispersing chemicals were biologically oxidized since these dyes are generally water insoluble.

Ammonia nitrogen removal through the system was good and was determined to be 68 percent for the total data analysis and 73 percent for the selective data analysis. This removal resulted from both utilization of the nitrogen by the biomass during synthesis and by conversion to nitrate nitrogen by nitrifying bacteria. The ratio of BOD removal to nitrogen removal was found to be 100:3.1 not considering the addition of supplemental ammonia or 100:4.0 when the addition is considered.

Orthophosphate was found to increase slightly through the system. This was attributed to sampling and analysis error, and it was then estimated that there was no measureable utilization of phosphorous by the biomass.

Dissolved solids removal across the process was determined to be 13 percent.

Of the heavy metals measured during the study period, only chromium was found to be removed by the activated sludge process. This removal was thought to be associated with the removal of dyes by the mechanisms proposed above since chromium is present as a constituent of the acid class of water soluble dyes used at the plant. Similarly, it was felt that the removal of hexavalent chromium below the detectable limit of the test method used during the study (0.02 mg/l) was due to dye removal rather than oxidation to the trivalent form.

The wastewater contained a detectable amount of phenolic compounds at about the concentration that would result in taste and odor problems in a water source. The process reduced this concentration by 73 percent to a level acceptable for discharge.

The process also removed a significant percentage of a number of trace inorganics such as calcium, magnesium, and potassium.

For the study period, the temperature difference across the system was 9.5°C or a heat loss rate of 3.1 million BTU per hour (0.78 million kilocalories per hour).

The dissolved oxygen level in the process discharge was determined to be 1.7 mg/l compared with an aeration basin level of 4.1 mg/l. The discharge level however was determined on a sample after the clarifier overflow weir and after some re-aeration had occurred. The data from several oxygen profile studies of the plant indicated a level of approximately 1.0 mg/l in the clarifier.

## PART B - OPERATING CHARACTERISTICS

Table XVI presents a summary of the activated sludge process operating characteristics.

An analysis of all the data collected during the study indicates a median aeration residence time of 14.4 hours, a median volatile mixed liquor suspended solids concentration of 2510 mg/l, a median biological loading rate of 0.30 pounds of BOD per pound of volatile mixed liquor solids, and a median volumetric loading rate of 43.2 pounds of BOD per thousand cubic feet (692 kg per 1000 cubic meters) of aeration basin volume.

The relationship between the biological loading to the process (F/M ratio) and the fraction of BOD remaining in the process effluent is presented in Figure XIII.

The data presented in this Figure and subsequent Figures is from selective monthly averages. Assuming an F/M ratio of 0.30, and an influent BOD of 448 mg/l, a BOD of 96 mg/l is obtained for the process discharge using Figure XIII.

Removal rates for BOD and COD were calculated using the mathematical model for activated sludge proposed by Eckenfelder and others(1):

$$(S_o)\ \frac{(S_o - S_e)}{X_v T} = KS_o \qquad (1)$$

where
$S_o$ = Influent substrate (mg/l)
$S_e$ = Effluent substrate (mg/l)
$X_v$ = VMLSS (mg/l)
$T$ = Aeration basin residence time (hr.)
$K$ = Rate constant

# TABLE XVI

## ACTIVATED SLUDGE OPERATING CHARACTERISTICS

| PARAMETER | YEARLY MEDIAN VALUE | YEARLY STANDARD DEVIATION | LOW MONTHLY AVERAGE VALUE | HIGH MONTHLY AVERAGE VALUE |
|---|---|---|---|---|
| AERATION RESIDENCE TIME (HOURS) | 14.4 | 19.4 | 12.8 | 48.4 |
| MIXED LIQUOR: | | | | |
| SUSPENDED SOLIDS (MG/L) | 2,928 | 814 | 2,285 | 4,508 |
| VOLATILE SUSPENDED SOLIDS (MG/L) | 2,510 | 691 | 2,172 | 3,906 |
| DISSOLVED OXYGEN (MG/L) | 4.1 | 3.2 | 2.2 | 10.9 |
| TEMPERATURE (°C) | 24.9 | 6.2 | 11.8 | 29.1 |
| SVI (ML/GM) | 125 | 54.8 | 68 | 243 |
| CLARIFIER OVERFLOW RATE (GAL/SQ.FT./DAY) | 280 | 112 | 127 | 364 |
| APPLIED F/M RATIO (MG/L PER MG/L VMLSS) | | | | |
| BOD | 0.30 | 0.19 | 0.07 | 0.45 |
| COD | 1.03 | 0.67 | 0.23 | 1.59 |
| REMOVAL RATE[a] (MG/L PER MG/L VMLSS PER HOUR AERATION) | | | | |
| BOD | 0.008 | 0.005 | 0.002 | 0.014 |
| COD | 0.013 | 0.013 | 0.002 | 0.024 |
| OXYGEN UP-TAKE RATE* (MG/L/HR) | 28.9 | | 12.9 | 44.4 |

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[a] AVERAGE VALUES ONLY AVAILABLE

This relationship is illustrated in Figures XIV and XV. In the case of BOD the rate was determined to be 0.0925 $hr^{-1}$ above a $S_e$ of 75 mg/l. Below that value the process is indicated to be severely substrate limited and the mathematical model is no longer applicable. For COD, the rate constant was found to be 0.086 $hr^{-1}$ above a $S_e$ of 900 mg/l.

Ammonia nitrogen removal is illustrated in Figure XVI in which the fraction of nitrogen remaining is plotted against the product of mixed liquor solids and aeration time and also the F/M ratio for BOD. The following nomenclature is used in this analysis:

$N_o$ = Influent ammonia nitrogen (mg/l)
$N_e$ = Effluent ammonia nitrogen (mg/l)
$X_v$ = VMLSS (mg/l)
T = Aeration basin residence time (days)
F/M = $S_o/X_vT$
$S_o$ = Influent BOD (mg/l)

The data in this Figure indicates that removal of ammonia nitrogen by synthesis of carbonaceous bacteria and by nitrification becomes substrate limited above a $X_vT$ of 1750 mg-day/l, and that the minimum value for the fraction of nitrogen remaining that can be obtained by the process is 0.175 mg/mg. Also, Figure XVI illustrates that the lack of carbonaceous material at a F/M ratio of less than 0.25 prevents nitrification.

Assuming $X_v$ = 2510 mg/l, T = 14.4 hours, and $N_o$ = 15.0 mg/l, a $N_e$ of 4.0 mg/l is calculated using the indicated relationship.

Color removal is illustrated in Figure XVII in which the fraction of color remaining is ploted against $X_vT$. The following nomenclature is used:

$C_o$ = Influent color (APHA units)
$C_e$ = Effluent color (APHA units)

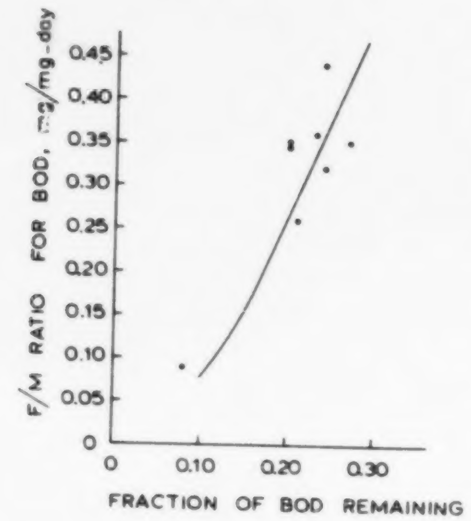


FIGURE XIII. Fraction BOD remaining

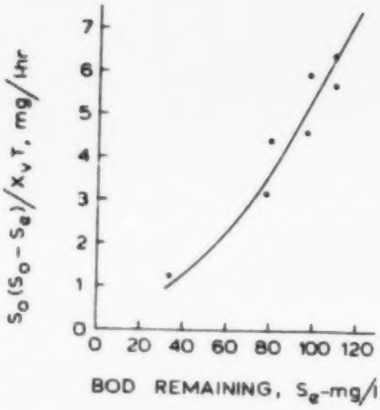


FIGURE XIV. BOD removal rate

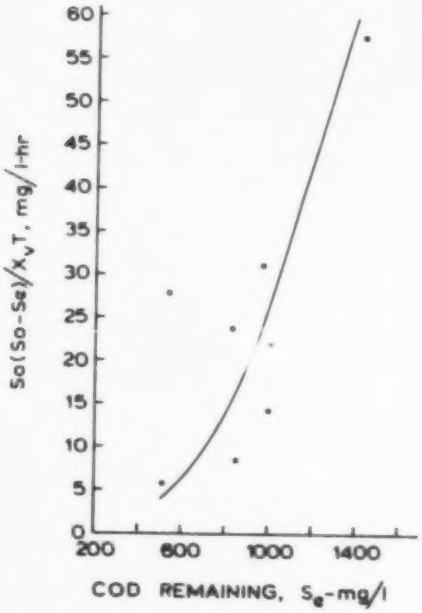


FIGURE XV. COD removal rate

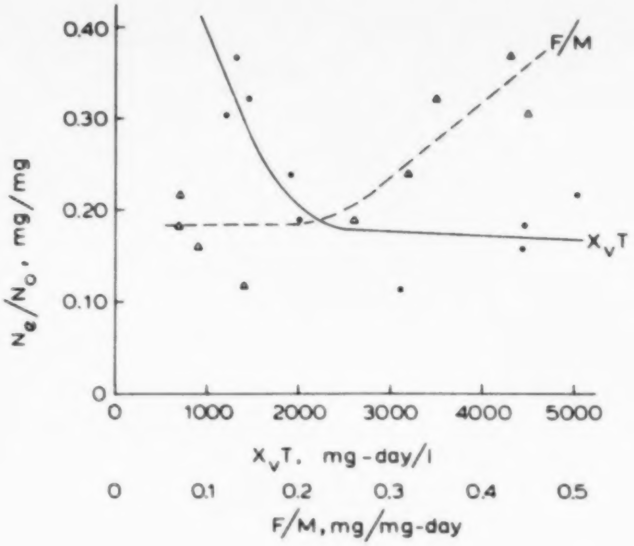


FIGURE XVI. Ammonia nitrogen removal rate

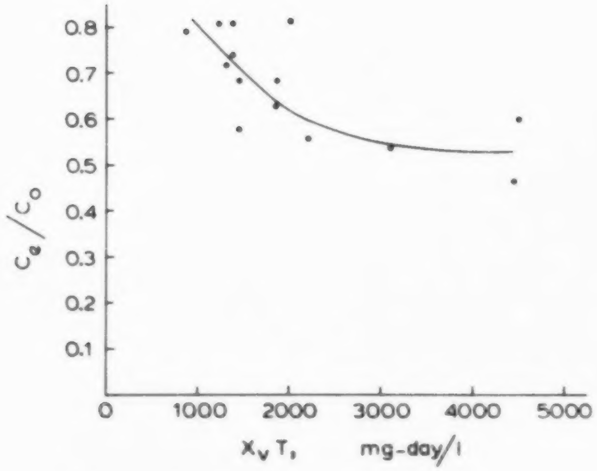


FIGURE XVII. Color removal rate

This Figure indicates that color removal by the activated sludge process is limited to a value of 52.5 percent of the initial color. Assuming $X_v$ = 2510 mg/l, T = 14.4 hours, and $C_o$ = 1032, $C_e$ is 722 APHA is calculated using the indicated relationship.

During the course of the study, the oxygen consumption (up-take) rate for the mixed liquor was measured. A sample was taken from the lagoon and a dissolved oxygen probe was immediately inserted in the container. Dissolved oxygen concentration was measured at one minute intervals over a fifteen minute period of time, and the consumption rate calculated. Oxygen consumption as a function of substrate removal was determined for the process using the mathematical model proposed by Eckenfelder and others(1):

$$(R_r)\ (V) = A(S_o - S_e)(Q) + B(X_v)(V) \qquad (2)$$

or

$$R_r/X_v = A\ (S_o - S_e)/X_vT + B \qquad (3)$$

where:

$R_r$ = Oxygen consumed (mg/l/day)
$S_o$ = Influent substrate (mg/l)
$S_e$ = Effluent substrate (mg/l)
T = V/Q = Aeration basin residence time (days)
A = Oxygen consumption rate due to synthesis
B = Oxygen consumption rate due to autoxidation

Figure XVIII presents this data and indicates values of A = 0.64 and B = 0.13 using BOD as the substrate. Very similar results were obtained using COD. Assuming $S_o$ = 448 mg/l, $S_e$ = 96 mg/l, $X_v$ = 2510, and T = 14.4 hours, an oxygen consumption rate of 29.3 mg/l/hr is obtained.

In addition to providing the required oxygen and mixing for the process, the aerator also serves as an air/water heat exchanger. Figure XIV illustrates the cooling affect of the aeration basin. The temperature change is shown to increase with aeration basin residence time, but the rate of cooling is shown to decrease with residence time. Assuming an aeration time of 14.4 hours and an initial temperature of 34.6°C, yields an effluent temperature of 25.5°C, and a heat loss rate of 1.9 million BTU per hour (0.48 million kilocalories per hour).

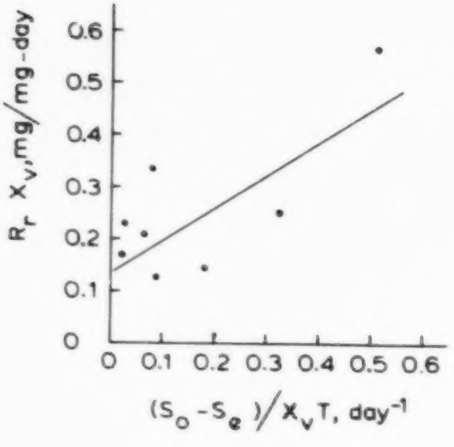


FIGURE XVIII. Oxygen consumption rate

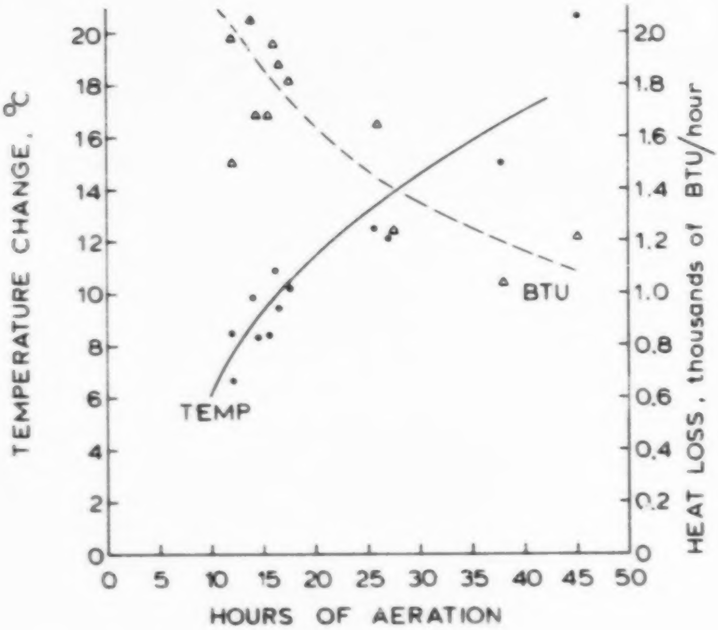


FIGURE XIX. Aeration basin cooling

The generation rate of excess biological solids as measured by waste sludge and net effluent solids was investigated using the following mathematical model:

$$X_aV = (X_e)\ (Q) + (X_e')\ (Q') = A'(S_o - S_e)\ (Q) + B'(X_v)(V) \quad (4)$$

or

$$\frac{X_a}{X_v} = \frac{(X_e)\ (Q) + (X_e')\ (Q')}{VX_v} = A'(S_o - S_e)/X_vT + B' \quad (5)$$

where:

$S_o$ = Influent substrate (mg/l)
$S_e$ = Effluent substrate (mg/l)
$T$ = $V/Q$ = Aeration basin residence time (days)
$V$ = Aeration basin volume (millions of gallons)
$Q$ = Influent flow (millions of gallons)
$Q'$ = Sludge flow (millions of gallons)
$A'$ = Sludge production rate due to synthesis
$B'$ = Sludge production rate due to autoxidation
$X_v$ = VMLSS (mg/l)
$X_e$ = Effluent biological suspended solids [Actual effluent solids minus influent solids] (mg/l)
$X_e'$ = Underflow suspended solids (mg/l)
$X_a$ = Biological solids accumulation (mg/l)

The data using BOD and COD as the substrate is presented in Figures XX and XXI respectively. Values of $A' = 0.625$ and $B' = 0.012$ were obtained for BOD removal. Values of $A' = 0.46$ and $B' = 0.12$ were obtained for COD removal. Assuming $S_o = 448$ mg/l BOD, $S_e = 96$ mg/l, $X_v = 2510$ mg/l and $T = 14.4$ hours, a sludge production rate of 943 pounds (428 kilograms) per day is calculated using Figure XXI.

An examination of the data indicated that there were was no removal of influent suspended solids through the process, and that there was a substantial carryover of biological solids in the clarifier. The performance of the clarifier in removing biological solids is illustrated in Figure XXII which plots effluent solids against total solids load. Biological solids were calculated as effluent minus influent TSS and MLSS minus influent TSS. The solids load was calculated based on the flow rate plus an assumed constant recycle rate of 0.20 MGD to the aeration lagoon. Assuming flow = 0.52 MGD (1968 cubic meters per day), $X = 2928$ mg/l, and influent TSS = 174 mg/l, and effluent TSS level = 324 mg/l is calculated.

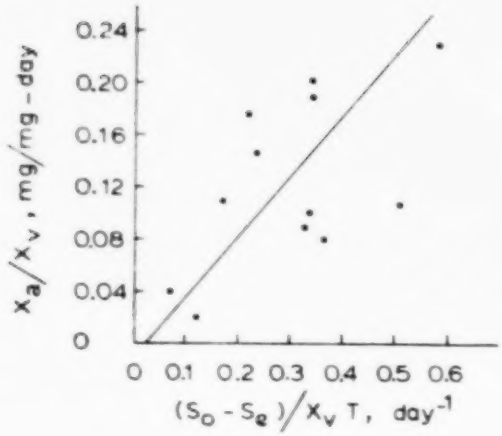


FIGURE XX. Sludge production rate based on COD removal

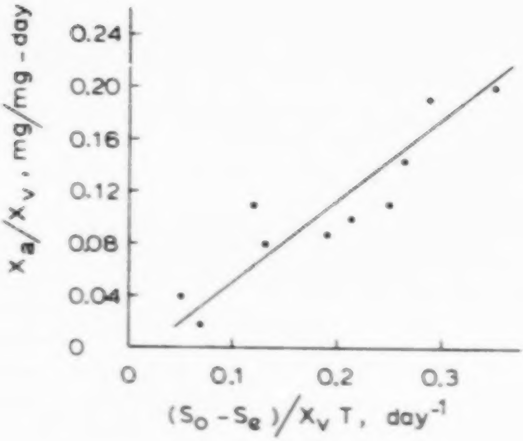


FIGURE XXI. Sludge production rate based on BOD removal

The variation in sludge volume index (SVI) with $X_vT$ is illustrated in Figure XXIII. The data indicates an optimum SVI of 90 ml/gr at a $X_vT$ of 2250 mg-day/l. A similar dependency of settling characteristics on MLSS concentration is illustrated in the static settling test results presented in Figure XXIV.

The underflow solids concentration of the biological sludge during the base study period averaged approximately 0.5 percent. However, it was judged that poor influent conditions to the clarifier adversely affected sludge thickening. After the completion of the study, modifications were made to the clarifier and as a result the average underflow concentration was increased to 1.5 percent solids.

Foaming in the aeration basin was a constant operational problem and as a result a chemical defoamer (Drew ED710) was added to the lagoon. The median dosage rate for this chemical was 24 mg/l. The defoamer used was an oil based chemical with a COD of 2.55 gm/gm and an oil content of 0.11 gm/gm.

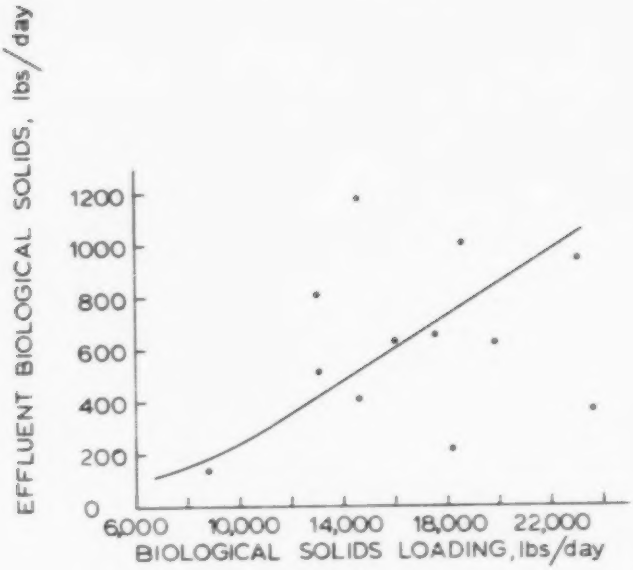


FIGURE XXII. Clarifier performance

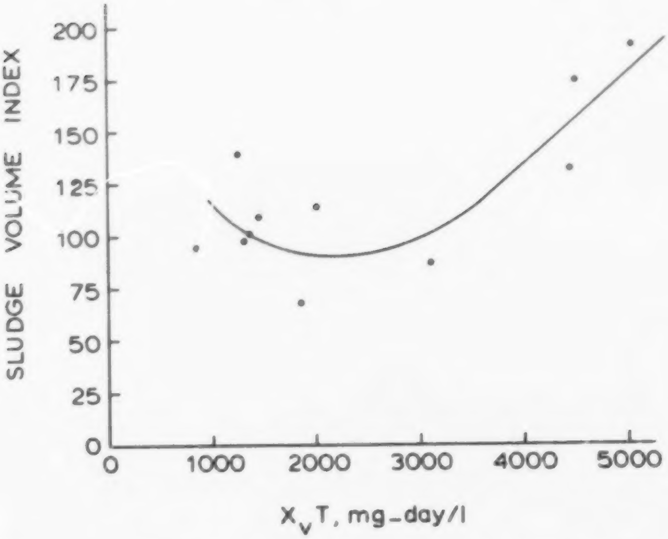


FIGURE XXIII. Variation in sludge volumn index

| CURVE | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| MIXED LIQUOR SUSPENDED SOLIDS (mg l l) | 3400 | 3600 | 2600 | 2600 | 1500 | 2600 |
| AERATION TIME (hours) | 14 | 13 | 14 | 12 | 15 | 71 |
| MIXED LIQUOR DISSOLVED OXYGEN(mg l l) | 4 | 2 | 4 | 2 | 1 | 2 |
| XvT(mg-day l) | 1983 | 1950 | 1517 | 1350 | 938 | 7692 |

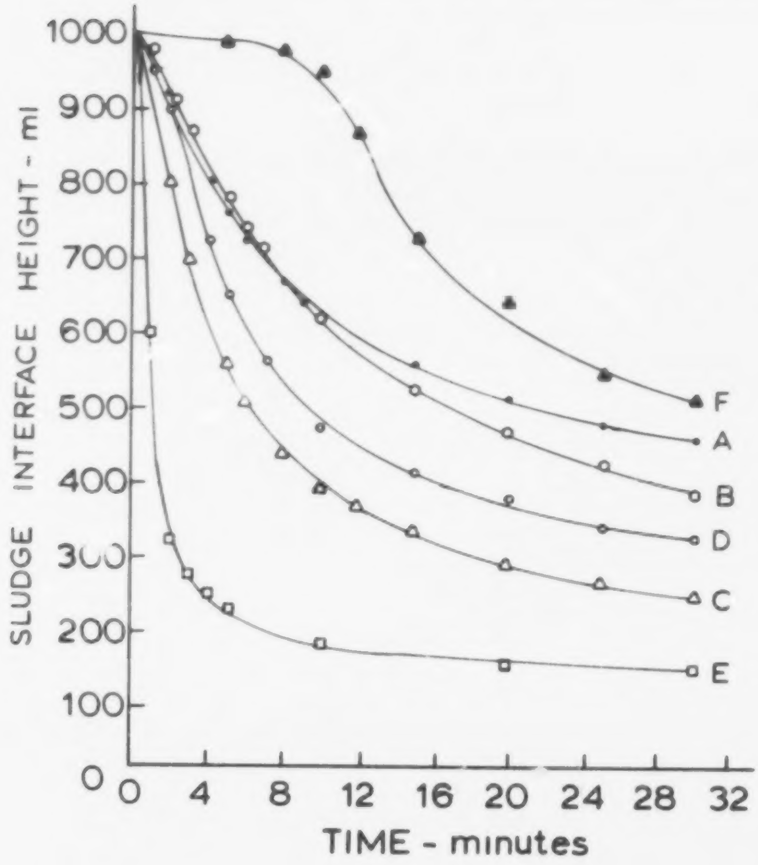


FIGURE XXIV. Static settling curves for the mixed liquor

# SECTION IX

## ALUM COAGULATION SYSTEM PERFORMANCE

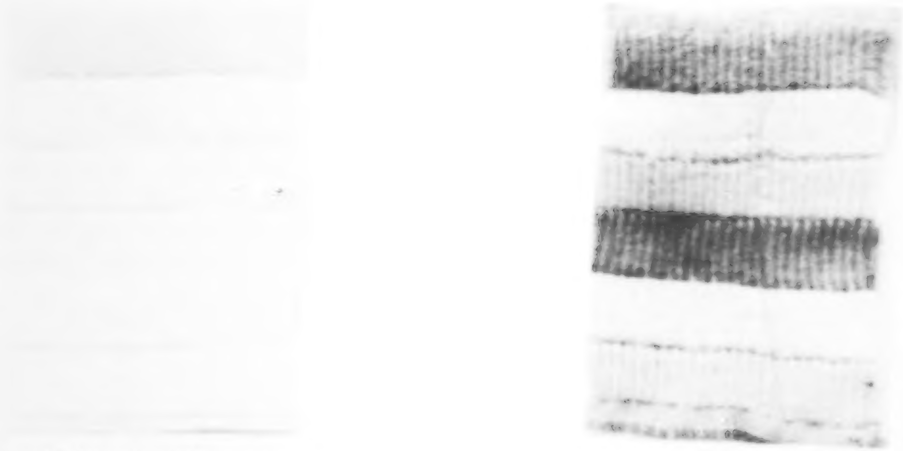
### PART A - EFFLUENT CHARACTERISTICS

Table XVII presents a summary of the alum coagulation effluent characteristics. Table XVIII presents a summary of the percentage removals for the process calculated from the influent and effluent median values. As in the previous section, both a total data and selective data analysis are presented.

The BOD removal through the process was determined to be 73 percent for the total data analysis and 75 percent for the selective data analysis. This removal was due primarily to the coagulation of suspended solids and to the destabilization and precipitation of colloidal material. The removal of soluble (less than 0.5 micron) BOD by the process was estimated to be 47 percent. Several analyses indicated that effluent $BOD_{20}$ was approximately twice the $BOD_5$ value.

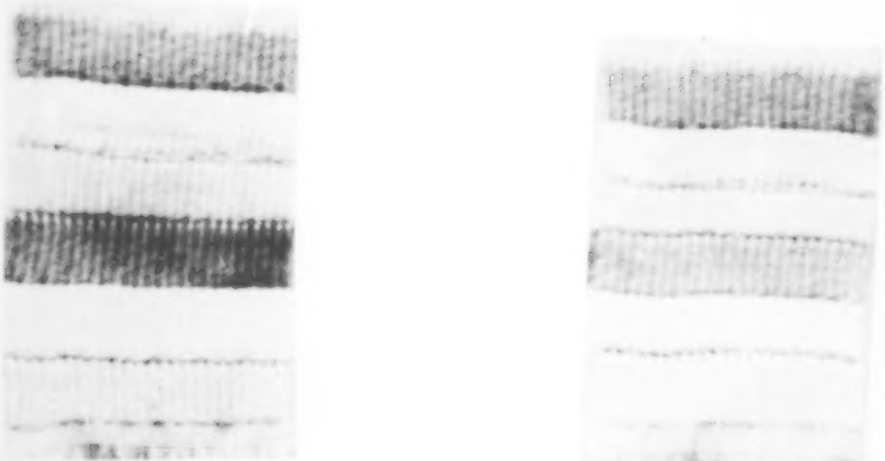
The COD removal through the process was determined to be 61 percent for the total data analysis and 58 percent for the selective data analysis. The significantly higher removal rate by this process in comparison with the activated sludge process indicates that the majority of wastewater COD is due to colloidal material removed by precipation and destabilization. The removal of soluble COD (less than 0.5 micron) by the process was estimated to be 51 percent.

Color removal by the process was found to be a substantial 60 percent based on total data analysis and 58 percent based on a selective data analysis. This color reduction was determined to be due primarily to the destabilization and agglomeration of dispersed dyes, although some precipitation of water soluble acid dyes was also indicated. A beaker scale dyeing procedure using the wastewater and a multiple fiber test fabric were used to qualitatively indicate the presence of the dispersed and acid types. Figure XXV is a photograph of a typical series of samples indicating slight removal of both acid and disperse dyes by the activated sludge process and the essentially complete removal of the disperse dyes and some removal of the acid dyes by the alum coagulation process. This result agrees with results of dyestuff removal by coagulation reported in the literature(14). Two representative spectrophotometric plots of the process effluent are presented in Figure XXVI.



A. Multiple fiber fabric
before dyeing

B. Fabric dyed with
equalized raw waste
(Color = 1290 APHA units)



C. Fabric dyed with
activated sludge effluent
(Color = 1050 APHA units)

D. Fabric dyed with alum
coagulation effluent
(Color = 220 APHA units)

**FIGURE XXV.** Color removal in the treatment system.

# TABLE XVII

## SUMMARY OF ALUM COAGULATION EFFLUENT CHARACTERISTICS

| CONTAMINANT | MEDIAN YEARLY VALUE | YEARLY STANDARD DEVIATION | LOW MONTHLY AVERAGE VALUE | HIGH MONTHLY AVERAGE VALUE |
|---|---|---|---|---|
| TEMPERATURE (°C) | 25.7 | 5.9 | 5.0 | 29.7 |
| PH | 6.2 | 1.3 | 4.4 | 6.7 |
| COLOR (APHA) | 320 | 281 | 116 | 601 |
| DISSOLVED OXYGEN (MG/L) | 4.8 | 3.2 | 2.5 | 7.1 |
| BOD (MG/L) | 33 | 87 | 14.5 | 98.0 |
| COD (MG/L) | 416 | 268 | 249 | 751 |
| SUSPENDED SOLIDS (MG/L) | 122 | 141 | 64 | 262 |
| VOLATILE SUSPENDED SOLIDS (MG/L) | 80 | 82 | 44 | 211 |
| DISSOLVED SOLIDS (MG/L) | 600 | 145 | 485 | 792 |
| AMMONIA NITROGEN (MG/L AS $NH_3N$) | 3.4 | 3.0 | 2.6 | 8.0 |
| ORTHOPHOSPHATE (MG/L AS $PO_4$) | 22.0 | 15.6 | 12.7 | 65.0 |
| ALUMINUM (MG/L) | 16.0 | - | 5.8 | 35.4 |
| CALCIUM (MG/L)[a] | - | - | 0.17 | 1.06 |
| CHROMIUM (MG/L) | 0.28 | - | 0.10 | 0.54 |
| HEXAVALENT CHROMIUM (MG/L)[a] | N.D. | - | - | - |
| COPPER (MG/L) | N.D. | - | N.D. | 0.03 |
| IRON (MG/L) | 0.68 | - | 0.35 | 2.18 |
| LEAD (MG/L)[a] | 0.023 | - | 0.003 | 0.050 |
| MAGNESIUM (MG/L)[a] | 1.47 | - | 0.84 | 3.40 |
| NICKEL (MG/L)[a] | 0.01 | - | N.D. | 0.02 |
| POTASSIUM (MG/L)[a] | 2.83 | - | 2.19 | 4.05 |
| SODIUM (MG/L)[a] | 1.48 | - | 71 | 333 |
| ZINC (MG/L) | 0.11 | - | 0.01 | 0.74 |
| MERCURY (MG/L)[a] | 0.0017 | - | 0.0001 | 0.003 |
| PHENOLICS (MG/L) | 0.04 | - | N.D. | 0.11 |
| TOC (MG/L) | 105 | - | 54 | 240 |
| CHLORIDE (MG/L)[a] | 46 | - | 42 | 56 |
| SULFATE (MG/L)[a] | 283 | - | 40 | 490 |
| ALKALINITY | 30 | - | 6 | 65 |

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[a] AVERAGE VALUES

## TABLE XVIII

## SUMMARY OF PERCENTAGE REMOVALS IN ALUM COAGULATION

| CONTAMINANT | REMOVAL BASED ON TOTAL DATA ANALYSIS (PERCENT) | REMOVAL BASED ON SELECTIVE DATA ANALYSIS (PERCENT) | EFFLUENT CONCENTRATION BASED ON SELECTIVE DATA ANALYSIS (MG/L) |
|---|---|---|---|
| BOD | 73 | 75 | 25 |
| COD | 61 | 58 | 380 |
| COLOR | 60 | 58 | 303 APHA |
| SUSPENDED SOLIDS | 67 | 70 | 104 |
| DISSOLVED SOLIDS | 3 | 3 | 600 |
| AMMONIA NITROGEN | 29 | 30 | 2.8 |
| ORTHOPHOSPHATE | 66 | 70 | 18.0 |
| ALUMINUM | (28) | (18) | 10.0 |
| CALCIUM | 42 | 42 | 0.86 |
| CHROMIUM | 22 | 44 | 0.20 |
| HEXAVALENT CHROMIUM | - | - | N.D. |
| COPPER | 100 | 100 | N.D. |
| IRON | (19) | (5) | 0.60 |
| LEAD | 18 | 18 | 0.023 |
| MAGNESIUM | 6 | 6 | 1.47 |
| NICKEL | 0 | 0 | 0.01 |
| POTASSIUM | 0 | 0 | 2.83 |
| SODIUM | 4 | 4 | 148 |
| ZINC | 50 | 50 | 0.05 |
| MERCURY | 6 | 6 | 0.0017 |
| PHENOLICS | (33) | 0 | 0.03 |
| TOC | 48 | 48 | 105 |
| CHLORIDE | 0 | 0 | 46 |
| SULFATE | (96) | (96) | 283 |
| ALKALINITY | 54 | 54 | 30 |

Orthophosphate removal, by precipitation as an aluminum salt, was determined to be a substantial 66 percent based on a total data analysis and 70 percent based on a selected data analysis.

Ammonia nitrogen removal was determined to be 29 percent, based on the total data anaylsis and was due to the removal of nitrogen containing colloidal organic matter.

Net dissolved solids removal across the process was determined to be 3 percent. However, considering the contribution of inorganic dissolved solids by the alum, the removal of process influent dissolved solids was estimated to be between 15 and 20 percent.

Chromium, copper, and zinc were found to be removed effectively by the alum coagulation process. The residual concentrations of copper and zinc were estimated to approach their solubility limits. Additional removal of chromium to a level of approximately 0.20 mg/l could be achieved, however, with an additional removal of dyes since the remaining dyes were most likely of the chromium metalized acid type. Mercury concentration was increased slightly probably as a result of the use of mercury contaminated liquid caustic soda for neutralization. Aluminum was increased 3.5 mg/l during the study as a result of the alum addition. This value is significantly higher than projected from the solubility data presented in Figure XXVII. Approximately 66 percent of the effluent aluminum was in the soluble form and the estimated increase in soluble aluminum through the process was 3.0 mg/l. The iron content of the waste was increased slightly as a result of the iron present as a contaminant in the alum.

There was an increase in phenol concentration across the process, as indicated by the data. This increase was due to sampling and analytical error considering the low concentration being measured.

The sulfate concentration of the wastewater was increased significantly as a result of non-complexed sulfate from the alum. Calcium, of the trace inorganics measured, was significantly reduced.

The pH was controlled to a level of 6.2 by caustic soda addition following alum addition, but there was a wide variation in effluent pH as indicated by a 2.3 pH unit standard deviation.

Alkalinity, primarily calcium alkalinity, was reduced 54 percent by the precipitation process.

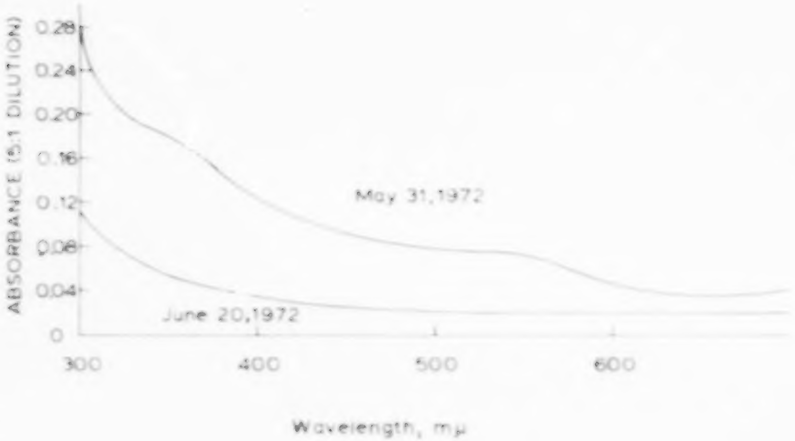
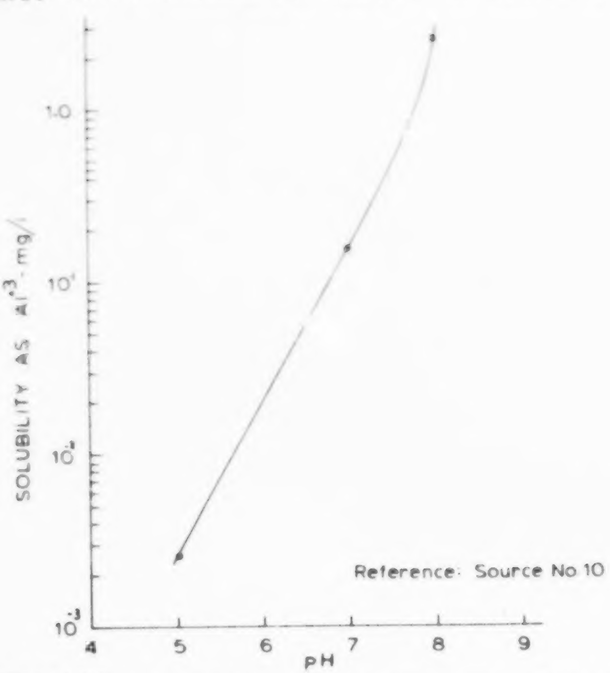


FIGURE XXVI. Spectrophotometric curves for alum coagulation effluent



Reference: Source No.10

FIGURE XXVII. Solubility in water of the mixed salt of aluminum, sulfate, and hydroxide

The dissolved oxygen in the process discharge was determined to be 4.8 mg/l. This measurement was at the final plant discharge after several weir overflow points. The data from several oxygen profile studies of the plant indicated a dissolved oxygen level of approximately 3.5 mg/l in the clarifier overflow. The increase in dissolved oxygen between the activated sludge and alum cuagulation clarifiers was attributed to re-aeration in the wastewater free fall line connecting the two units.

## PART B - OPERATING CHARACTERISTICS

Table XIX presents a summary of the alum coagulation operating characteristics.

An analysis of all the data indicated a median alum dosage of 263 mg/l. After the polymer feed system was placed in operation, the median dosage of the anionic polymer was 3.9 mg/l.

The coagulation process (that is the formation of colloidal particles and the aggregation of existing and newly formed particles) is dependent on two principle events:

- particle transport to effect interparticle contact
- particle destabilization to permit attachment when contact occurs

The first event involves the selection of structures and mixing equipment and the second event involves the selection of a coagulant and the process conditions (13).

In evaluating the performance of the activated sludge system, two separate analyses were made. The first analysis was to determine the optimum coagulant dose range as indicated by beaker scale ("Jar") tests that approximate the full-scale treatment method. The second analysis was to determine the removal rate characteristics in the full-scale system to predict performance based on the use of the effective range of coagulant dose.

Figure XXVIII presents the data for a typical series of jar tests in which supernatant BOD and COD was measured at various alum dosage levels. This data indicates an alum dosage of 200 - 300 mg/l was required in order to achieve maximum removal. At a dosage of over 300 mg/l the additional alum provided no further significant removal. At a dosage of under 200 mg/l contaminant removal decreased rapidly and a turbid supernatant was produced.

Contaminant removal was also found to be dependent on supernatant pH. Figure XXIX illustrates this for BOD and COD values and indicates an optimum pH of 5.0 for an alum dose of 300 mg/l (the pH resulting from an alum dose of 300 mg/l without the pH adjustment would be 3.8 - 4.0).

## TABLE XIX

## ALUM COAGULATION OPERATING CHARACTERISTICS

| PARAMETER | YEARLY MEDIAN VALUE | YEARLY STANDARD DEVIATION | LOW MONTHLY AVERAGE VALUE | HIGH MONTHLY AVERAGE VALUE |
|---|---|---|---|---|
| ALUM DOSAGE (MG/L) | 263 | 103 | 206 | 358 |
| ANIONIC POLYMER DOSAGE(a) (MG/L) | 3.9 | 2.3 | 2.94 | 4.72 |
| CLARIFIER OVERFLOW RATE (GAL/SQ.FT./DAY) | 364 | 141 | 198 | 485 |
| REMOVAL RATE (MG/L PER MG/L OF ALUM) | | | | |
| BOD[b] | 0.34 | - | 0.27 | 0.76 |
| COD[b] | 2.18 | - | 1.23 | 6.93 |
| COLOR | 1.4 | 2.4 | 0.92 | 2.4 |

NOTE:

[a] AFTER MAY 1, 1973 ONLY

[b] AVERAGE VALUES

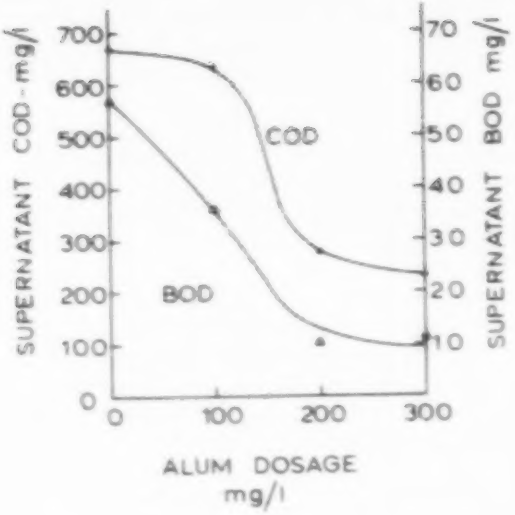


FIGURE XXVIII. Typical COD and BOD removals by alum coagulation at a pH = 6.0

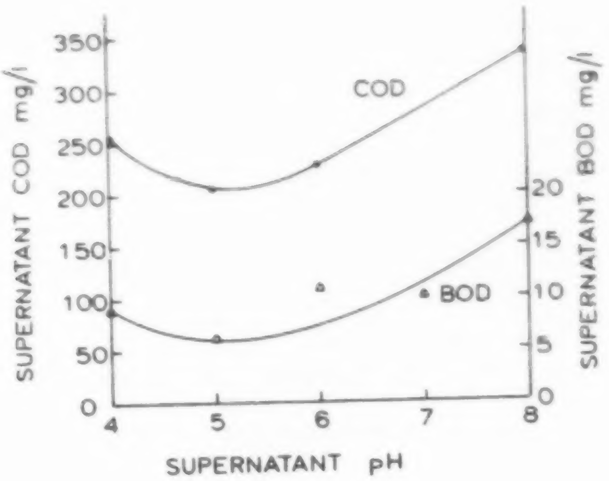


FIGURE XXIX. Typical COD and BOD removals with pH at an alum dose of 300 mg/l

Similar data is presented in Figures XXX through XXXII for color, orthophosphate, aluminum, and chromium. For color an optinum alum dosage of over 225 mg/l was indicated with a maximum insolubility at 5.0 pH. For orthophosphate an optimum alum dose of 300 mg/l was indicated with a maximum insolubility at 5.0 - 6.5 pH. For aluminum and chromium, maximum insolubility was indicated at 6.0 pH.

The data presented in these graphs are typical of the results obtained during the study and indicate an alum dosage of 200-300 mg/l is required to obtain effective coagulation. The data also indicates that there are two separate pH points (5.0 and 6.0) for maximum insolubility of the contaminants (this is further discussed in Section XVII of this report).

In order to insure that the proper coagulant dose is applied to the wastewater in a chemical treatment process, periodic jar test analyses are required. During the course of the study, these tests were made periodically and the results tended to substantiate the 200 - 300 mg/l dose as the optimum.

Before proceeding further, it may be helpful to review several general concepts of coagulation that have been discussed in the literature in recent years. O'Melia indicates the following four methods of metal salt coagulation:(13)

- compression of the diffuse charge layer surrounding colloidal particles by attraction of counter ions
- adsorption of metal ions into the colloid to produce charge neutralization
- enmeshment of the colloid in a precipitate
- adsorption of a polymeric species by the colloid to permit interparticle bridging

For wastewater treatment, only the latter two methods may be significant.

When a metal salt is used as a coagulant in sufficient concentration to cause rapid precipitation, colloidal particles can be enmeshed in the precipitate as it is formed. The rate of colloid removal by this method is influenced by the degree of over-saturation of the solution, the presence of multivalent anions, and the concentration of the colloid. That is, the higher the degree of saturation or the concentration of the anion or the concentration of the colloid, the lower the amount of coagulant required to affect removal(13).

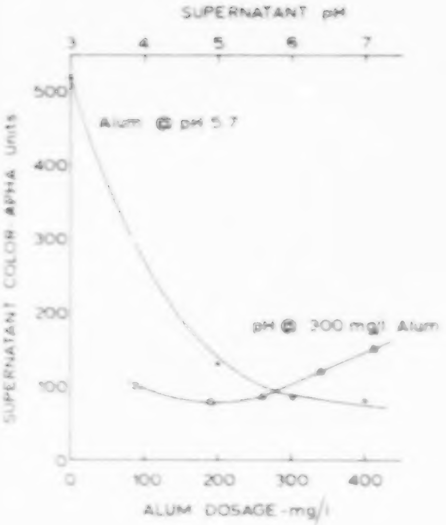


FIGURE XXX. Typical color removal variations with alum dose at pH

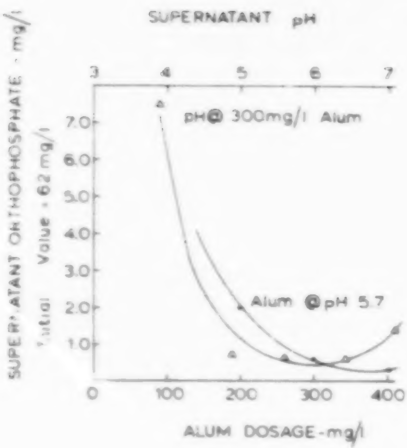


FIGURE XXXI. Typical orthophosphate removal variation with alum dose at pH

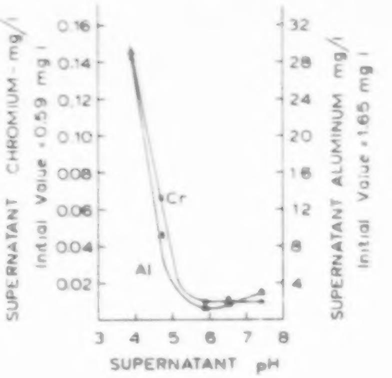


FIGURE XXXII. Residual aluminum and chromium variation with pH at an alum dose of 400 mg/l.

Coagulation by interparticle bridging occurs when a colloid contacts a polymer species and absorbs some of the chemical groups of the polymer while leaving other groups available for adsorption by remaining colloids.

The water chemistry of aluminum (III) is a complex subject even when the solute is pure water. Hayden mentions the following concepts, however, as the major factors whicb.significantly affect the understanding of the process:(10)

- The species and state of aluminum (III) that can be formed during coagulation are pH dependent as indicated by Figure XXXIII, and these species affect the method of coagulation experienced
- For pure water, the pH point of precipitation ($pH_p$) varies between 4.2 and 4.9 depending on concentration Simarily the pH point of dissolution ($pH_d$) varies between 9.6 and 11.5 and the pH point of destabilization ($pH_c$) varies between 6.0 and 7.0
- Below a pH of 4.0 the principal species is the soluble free metal ion Al (III)
- Just prior to the pHp point, the principal species is the soluble, cationic polymeric species $Al_8(OH)_{20}^{4+}$
- Past the $pH_d$ point, the principle species is the soluble, anionic species of $Al(OH_4)^-$
- Between the $pH_p$ and $pH_d$ points the species present is $Al(OH)_3$ and in this range the precipitate may be a colloid suspension or a settelable solid depending on pH, concentration of aluminum (III), and the presence of anions (particularly polyvalent anions)
- The presence of polyvalent anions in sufficient concentration tend to decrease the $pH_p$ and $pH_c$ points by formation of complex aluminum/hydroxide/anion salts

Referring again to O'Melia and Figure XXIV, the method of coagulation that is observed is a function of the dosage of coagulant and the colloid concentrations when pH and anion concentration are constant. For concentration $S_1$, destabilization occurs only when sufficient

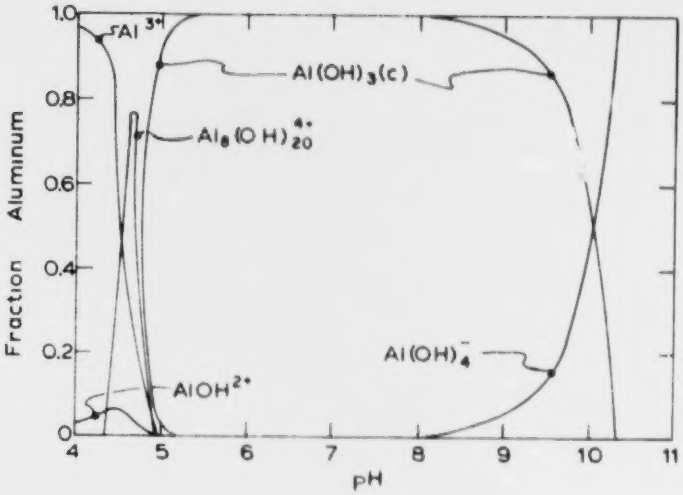


FIGURE XXXIII. Distribution of hydrolyzed aluminum (III) as a function of pH and a $1.0 \times 10^{-3}$ molar concentration of aluminum (III)

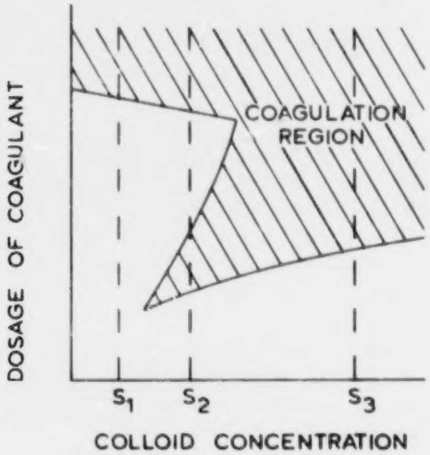

DOSAGE OF COAGULANT
COAGULATION REGION
$S_1$
$S_2$
$S_3$
COLLOID CONCENTRATION

FIGURE XXXIV. Schematic representation of coagulation

coagulant has been added to obtain oversaturation and enmeshment of the colloid in the hydroxide precipitate. For concentration $S_2$, destabilization can occur either at the oversaturation level, or at a much lower concentration by the adsorption of hydrometal polymers. For $S_3$, the colloid concentration is sufficiently high that destabilization can only occur by adsorption of hydrometal polymers.

Based on the voluminous sludge produced by the coagulation process, in comparison with the small fraction of colloidal chemicals and dyes in the BRW wastewater, it is estimated that the mechanism observed in the full-scale coagulation process is primarily due to oversaturation and generation of aluminum hydroxide solids. This agrees with the data presented by Hayden, in that a settleable floc rather than a suspension will be produced because the sulfate concentration experienced in the BRW wastewater depresses the $pH_c$ point to the $pH_p$ point.

However, since the optimum pH point for organic chemical and color removal is in the range of 5.0, it may be possible that additional destabilization occurs through the adsorption of the cationic, polymeric species of aluminum that exist in this pH range. Also, it may be possible that these cationic polymers chemical interact with the anionic acid dyestuffs and form an insoluble basic salt. This latter method has been observed in the removal of naturally occuring organic color from water(4).

The data in Figure XXXI indicates that a ratio of 1.6 moles of Al (III) per mole of phosphorous is required to remove phosphate below a level of 1.0 mg/l (as $PO_4$). This ratio is similar to that reported in the literature (11). The pH effect indicated generally agrees with published information that the range for destabilization of aluminum/phosphate precipitates is pH 4.5 - 7.0 (10).

Figure XXXII indicates a residual aluminum of 1.0 mg/l at the optimum pH of 6.0 although the literature indicates that a residual of 0.1 mg/l should be obtained at this pH(10). The solubility of chromium as indicated by the literature (12) is substantially higher than the values illustrated in Figure XXXII and suggest that the measured chromium is complexed with the acid dyes rather than present in a free ion state.

After establishing that sufficient alum was present to cause coagulation, it was possible to examine contaminant removal characteristics in the full system for periods when the alum dose was within the effective range.

An analysis of the data for the coagulation process determined that for BOD, COD, and color the only significant correlation was between the removal rate per mg/l of alum and the influent concentration of contaminant. Figures XXXV through XXXVII illustrate this relationship and indicate the generally increasing rate of removal with higher initial concentration of contaminant. This relationship is in agreement with the theory previously presented. Figures XXXV through XXXVII have been projected to a zero removal rate to indicate estimate minimum obtainable effluent values for the coagulation process.

Using these graphs and assuming alum dose and influent values, effluent concentrations are calculated as presented in Table XX.

## TABLE XX

## PREDICTED REMOVALS BY ALUM COAGULATION

| ALUM DOSE (MG/L) | CONTAMINANT | INFLUENT VALUE | EFFLUENT VALUE |
|---|---|---|---|
| 275 | BOD (MG/L) | 100 | 26 |
| 275 | COD (MG/L) | 900 | 405 |
| 275 | COLOR (APHA) | 725 | 340 |

The removal of orthophosphate was found to be relatively constant (0.14 gr phosphate per gr of alum or 0.44 moles of phosphorous per mole of aluminum) and no correlation was found between alum dosage, removal rate, or influent or effluent phosphate values.

Assuming an influent orthophosphate concentration of 60 mg/l, an alum dosage of 275 mg/l, the calculated effluent orthophosphate concentration would be 21 mg/l.

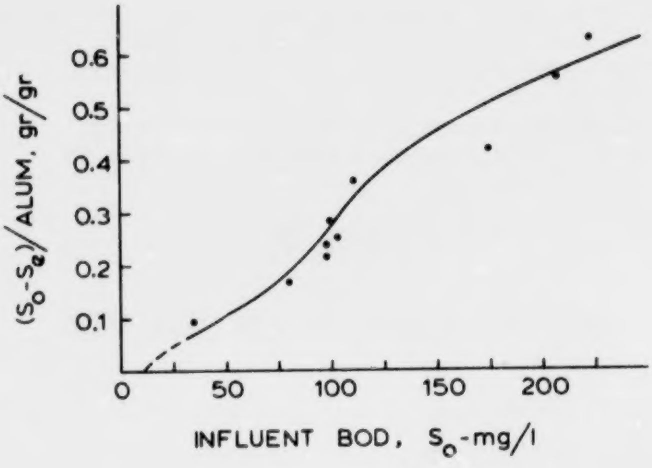


FIGURE XXXV. BOD removal by alum

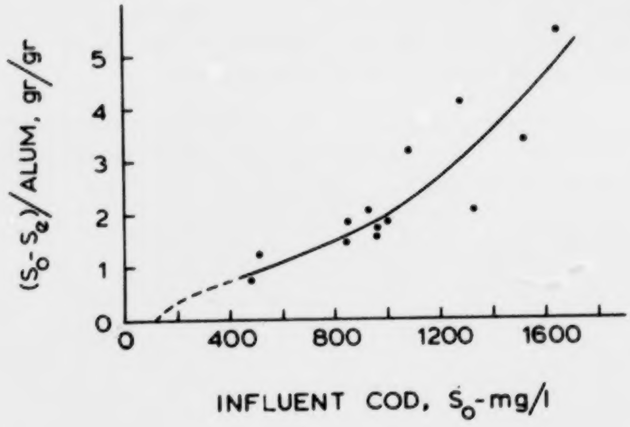


FIGURE XXXVI. COD removal by alum

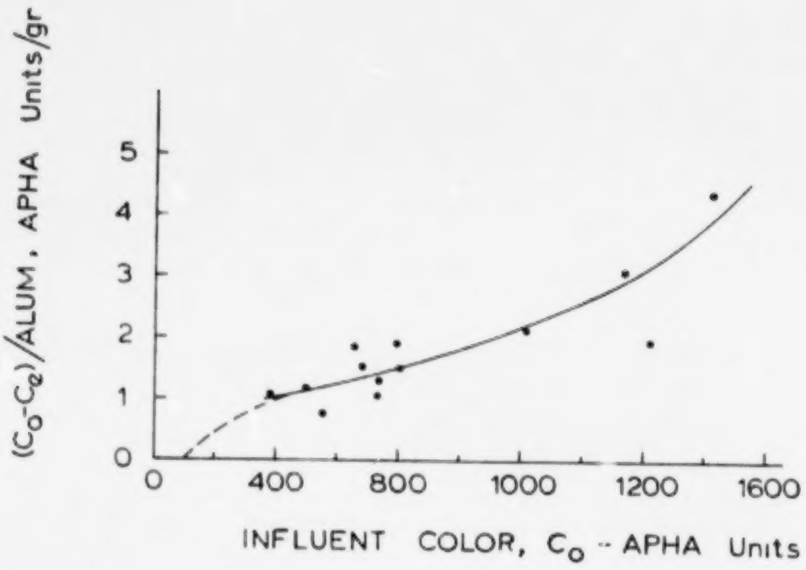


FIGURE XXXVII. Color removal by alum

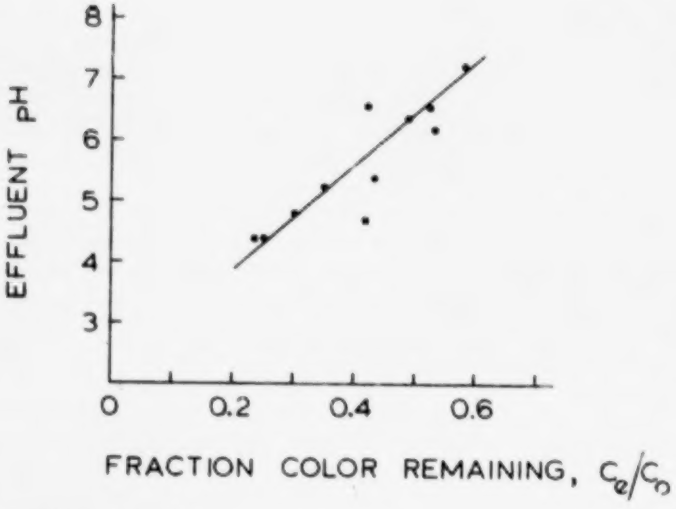


FIGURE XXXVIII. Color removal as a function of pH

Jar tests of the alum coagulation process indicated increased color removal at a pH in the 4.75 - 5.25 range. Figure XXXVIII illustrates a similar result using treatment plant performance data. In this presentation, the effluent color values were mathematically adjusted to a value representing color at a pH of 6.5 by the use of Figure IX in Section V of this report. This data indicates that by lowering the pH of the coagulation process from 6.5 to 5.0, the fraction of color remaining will be reduced to 65.0 percent of the 6.5 pH color value. Therefore, based on the previous example, an effluent color of 340 APHA units at a 6.5 pH would be reduced to 200 APHA units at a 5.0 pH.

Figure XXXIX illustrates the performance of the alum coagulation clarifier in removing suspended solids.

For this presentation, solids loading to the clarifier was calculated as pounds of influent suspended solids. Effluent solids was calculated as pounds of suspended solids in the clarifier overflow. The data indicates a substantially lower removal rate at wastewater pH values below 4.5.

Assuming an influent suspended solids concentration of 330 mg/l and a flow rate of 0.52 MGD (1968 cubic meters per day), the calculated effluent suspended solids concentration would be 90 mg/l according to Figure XXXIX.

The alum sludge generation rate is presented in Figure XL where solids added are plotted against solids lost from the clarifier. For this presentation, solids added was calculated as the total of influent suspended solids and alum dose in pounds, and the solids lost was calculated as the suspended solids lost over the weir plus the suspended solids in the sludge underflow in pounds.

Assuming an influent suspended solids concentration of 330 mg/l, a flow rate of 0.52 MGD (1968 cubic meters per day), an alum dosage of 275 mg/l, a solids underflow concentration of 20,000 mg/l, the calculated sludge flow would be 8,200 gallons (31.0 cubic meters) per day.

Typical settling curves for the alum generated sludge are presented in Figure XLI. The effects of rapid mixing and polymer addition are illustrated in this Figure. Without rapid mixing of the alum and wastewater or without polymer addition, the initial settling rate was 38.5 mls per minute after five minutes of non-settling. With rapid mixing, the settling rate was increased to 125 mls per minute, the non-settling time reduced to three minutes. With rapid mixing and anionic polymer addition, the settling rate was increased to 400 mls per minute, and the non-settling period eliminated.

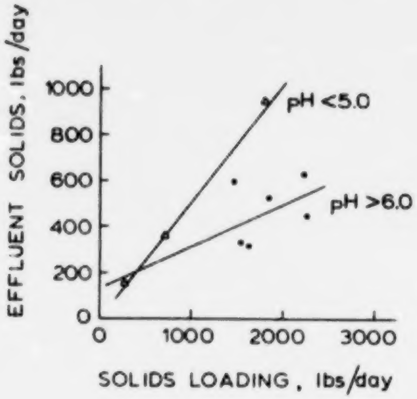


**FIGURE XXXIX.** Alum coagulation clarifier performance

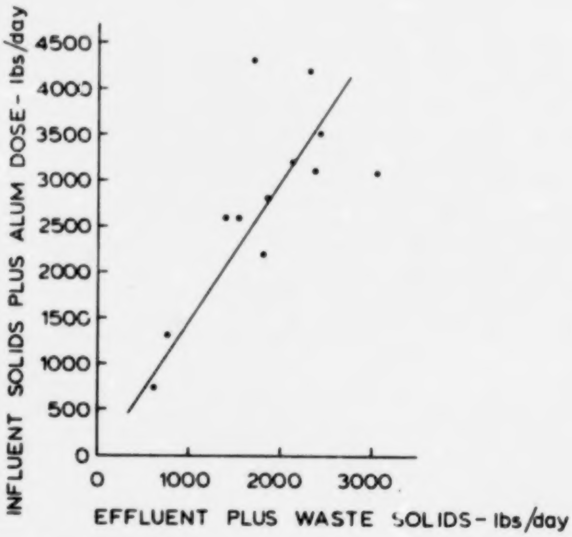


**FIGURE XL.** Alum sludge generation

| | A | B | C | D | E |
|---|---|---|---|---|---|
| SLOW MIX | YES | YES | YES | NO | NO |
| RAPID MIX | NO | NO | YES | YES | YES |
| POLYMER ADDITION | NO | NO | NO | YES | YES |

| TIME | SUPERNATANT SUSPENDED SOLIDS DURING TEST "E" |
|---|---|
| 0 MIN | 510 mg/l |
| 2 MIN | 15 mg/l |
| 15 MIN | 14 mg/l |
| 60 MIN | 11 mg/l |

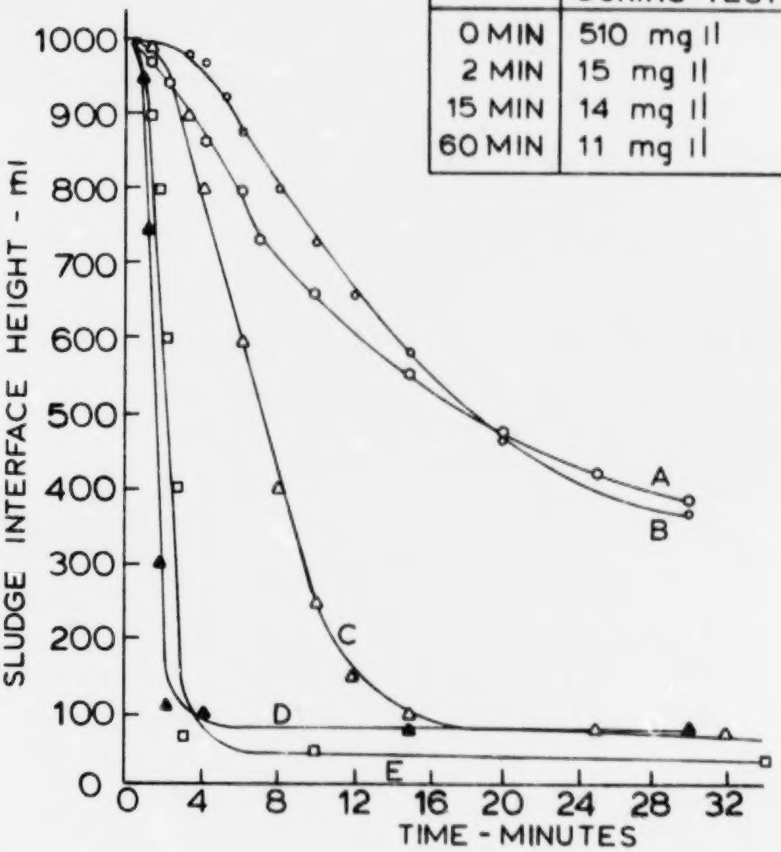


FIGURE XLI. Static settling curves for alum sludge

The adverse effect of pH in suspended solids removal in the alum coagulation clarifier is illustrated in the treatment plant performance data presented in Figure XLII. This data indicates that by lowering the wastewater pH from 6.5 to 5.0, the fraction of solids remaining will be increased from 0.21 to 0.45.

The neutralization requirement for the coagulation process is illustrated in Figure XLIII, which presents titration data for activated sludge effluent using alum to titrate downward and sodium hydroxide to titrate upward. In this example, an alum dosage of 275 mg/l would lower the wastewater pH to 4.5 and would require 40 mg/l of sodium hydroxide to adjust the wastewater to 6.5 pH.

In Section VI of this report, the new rapid mix, slow mix, and polymer injection additions to the alum coagulation process were discussed. While an analysis of the data indicates a barely detectable increase in contaminant removal, a major change that occurred was in the thickening of solids in the clarifier and an order of magnitude increase in underflow solids concentration. Prior to the modification an average underflow solids concentration of 2317 mg/l required an average underflow pumping rate of twelve percent of through-put flow. After the modification, an average underflow concentration of 19,584 mg/l required only an average underflow rate of three percent of through-put flow.

The turbidity values for the alum coagulation clarifier effluent for the month prior to the mixing and polymer modifications and for the two months after the modifications were examined. This data indicates that turbidity in the effluent was reduced from a median of 110 JTU to a median of 55 JTU by installation of rapid mix and polymer addition facilities.

The effluent from the activated sludge clarifier typically contained a dissolved oxygen residual of 0.5 - 2.0 mg/l. Prior to the installation of the new mixing and polymer addition equipment to the alum coagulation system, this concentration was increased to a 4.0 - 5.0 mg/l level due to the piping arrangement between the activated sludge and alum coagulation clarifiers. The difference in elevation between the clarifier water surfaces exceeded eight feet (2.4 meters), and a large volume of air was entrained in the wastewater as it flowed down a vertical section of pipe at the activated sludge clarifier exit. When the new mixing equipment was installed, the hydraulics were improved but at the expense of the dissolved oxygen concentration. As a result, dissolved oxygen was depleted in the wastewater as degradation of organic matter continued in the clarification step.

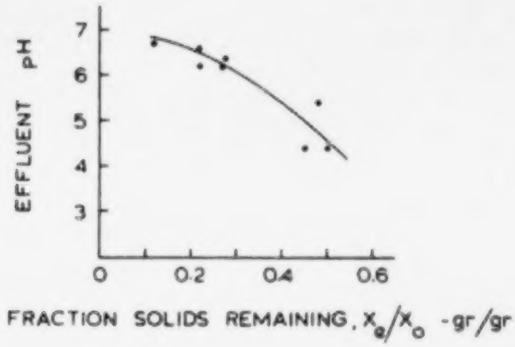


**FIGURE XLII.** Suspended solids removal as a function of pH

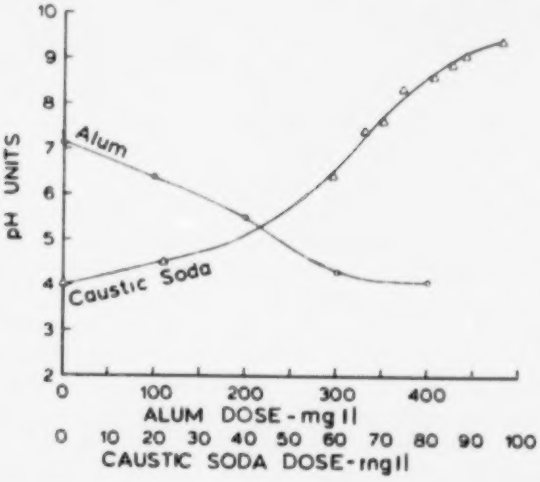


**FIGURE XLIII.** Titration of activated sludge system effluent with alum and caustic soda

To correct this situation, hydrogen peroxide was added to the discharge end of the flocculation basin. A dosage rate of 15 mg/l was found to provide a sufficient residual to prevent septic odor formation without a detectable peroxide residual in the effluent.

# SECTION X

# COMBINED ACTIVATED SLUDGE AND ALUM COAGULATION SYSTEM PERFORMANCE

A summary of overall removal rates for the combined activated sludge and alum coagulation system is presented in Table XXI for both a total data analysis and a selective data analysis. Also, effluent contaminant to production weight ratios for the contaminants listed in the July 5, 1974, EPA textile industry guidelines have been calculated and are presented in Table XXII.

Observation of the performance of the combined system resulted in the following conclusions regarding total system capabilities:

- Soluble and colloidal biodegradable organic chemicals, expressed as BOD, were removed to a high degree
- Colloidal, refractory organic chemicals, expressed as total COD, were removed to a high degree. There was only partial removal of soluble, refractory organic chemicals, expressed as soluble COD
- Dispersed dyes were effectively removed by the system but only partial removal of acid dyes was accomplished as indicated by color measurement and qualitive dye analysis
- Only minimal removal of dissolved solids was accomplished
- Ammonia nitrogen was removed to a high degree by the system, primarily by the activated sludge process
- Orthophosphate was removed by the alum coagulation process, but the high influent concentration resulted in significant phosphate in the effluent
- Total chromium, hexavalent chromium, copper, and zinc were effectively reduced by the system. However, aluminum, iron, and mercury were increased by the system.

## TABLE XXI

## SUMMARY OF TOTAL SYSTEM REMOVAL RATES

| CONTAMINANT | BASED ON TOTAL DATA ANALYSIS (PERCENT) | BASED ON SELECTIVE DATA ANALYSIS (PERCENT) |
|---|---|---|
| BOD | 92 | 94 |
| COD | 73 | 76 |
| COLOR | 69 | 71 |
| SUSPENDED SOLIDS | 30 | 40 |
| DISSOLVED SOLIDS | 16 | 16 |
| AMMONIA NITROGEN | 77 | 84 |
| ORTHOPHOSPHATE | 63 | 70 |
| ALUMINUM | (88) | NOT PREDICTED |
| CALCIUM | 57 | 51 |
| CHROMIUM | 52 | 65 |
| HEXAVALENT CHROMIUM | 100 | 100 |
| COPPER | 100 | 100 |
| IRON | (45) | (45) |
| LEAD | 8 | 8 |
| MAGNESIUM | 39 | 39 |
| NICKEL | 0 | 0 |
| POTASSIUM | 33 | 33 |
| SODIUM | 4 | 4 |
| ZINC | 15 | (60) |
| MERCURY | (6) | (6) |
| PHENOLICS | 60 | 60 |
| TOC | 72 | 72 |
| CHLORIDE | (6) | (6) |
| SULFATE | (79) | (79) |
| ALKALINITY | 71 | 71 |
| DETERGENT | 88 | 90 |
| FOAMING | | |
| HEIGHT | (42) | NOT PREDICTED |
| DURATION | 32 | NOT PREDICTED |

## TABLE XXII

## EFFLUENT CONTAMINANT TO PRODUCTION WEIGHT RATIOS BASED ON SELECTED DATA ANALYSIS

| CONTAMINANT | CONCENTRATION (MG/L) | RATIO (LBS/1000 LBS OR KG/KKG) |
|---|---|---|
| BOD | 25 | 2.24 |
| COD | 380 | 34.05 |
| SUSPENDED SOLIDS | 104 | 9.26 |
| TOTAL CHROMIUM | 0.20 | 0.018 |
| PHENOL | 0.03 | 0.003 |

BASIS:

FLOW = 0.520 MILLION GALLONS (1968 CUBIC METERS) PER DAY

PRODUCTION = 48,400 POUNDS (21,950 KILOGRAMS) PER DAY

- Phenolic chemicals were reduced to an acceptable discharge primarily by the activated sludge process

- Calcium, magnesium, and potassium were significantly reduced but sulfate was increased by the system

- The alkalinity of the discharge was reduced significantly by the system

- Detergent concentration, measured as MBAS, was very effectively reduced by the system. However, there was essentially no change in the characteristic of the wastewater to produce a noticeable amount of long duration foam when agitated.

Based on the waste characteristics and operating characteristics presented in Table XXIII and using the performance models for the treatment processes previously presented, the effluent characteristics and operating parameters for the system have been predicted. The calculations for this process design are presented in Tables XXIV through XXVI. A process material balance using the data from this process design is presented in Table XXVIII.

# TABLE XXIII

## BASIS OF PROCESS DESIGN CALCULATIONS

| | |
|---|---|
| FLOW (MGD) | 0.52 |
| EQUALIZED WASTE CONTAMINANTS | |
| BOD (MG/L) | 450 |
| COD (MG/L) | 1550 |
| COLOR (APHA) | 1030 |
| AMMONIA NITROGEN (MG/L) | 15 |
| ORTHOPHOSPHATE (MG/L) | 60 |
| SUSPENDED SOLIDS (MG/L) | 175 |
| TEMPERATURE (°C) | 35 |
| OPERATING CHARACTERISTICS | |
| MLSS (MG/L) | 2950 |
| VMLSS (MG/L) | 2500 |
| RETURN SLUDGE RECYCLE RATE (MGD) | 0.17 |
| ACTIVATED SLUDGE CLARIFIER UNDERFLOW SOLIDS CONCENTRATION (%) | 1.5 |
| ALUM COAGULATION CLARIFIER UNDERFLOW SOLIDS CONCENTRATION (%) | 2.0 |
| ALUM DOSE (MG/L) | 300 |

# TABLE XXIV

## PROCESS DESIGN CALCULATIONS
## FOR CONTAMINANT REMOVAL

Activated Sludge Process (see Section VIII for development of relationships).

A. BOD Removal

$$S_o\,(S_o - S_e)/X_vT \;=\; 0.0925\,S_e - 3.8$$
$$450(450 - S_e)/(2500)(15.5) \;=\; 0.0925\,S_e - 3.8$$
$$5.22 - 0.0116\,S_e \;=\; 0.0925\,S_e - 3.8$$
$$9.02 \;=\; 0.104\,S_e$$
$$S_e = 87 \text{ mg/l}$$

B. COD Removal

$$S_o\,(S_o - S_e)/X_vT \;=\; 0.086\,S_e - 60$$
$$1550\,(1550 - S_e)/(2500)(15.5) \;=\; 0.086\,S_e - 60$$
$$62 - 0.040\,S_e \;=\; 0.086\,S_e - 60$$
$$122 \;=\; 0.126\,S_e$$
$$S_e = 968 \text{ mg/l}$$

C. Color Removal

$$X_vT \;=\; (2500)(15.5)/24 \;=\; 1615 \text{ mg-day/liter}$$
$$@X_vT \;=\; 1615,\; C_c/C_o \;=\; 0.68 \text{ (See Figure XVII)}$$
$$C_e \;=\; (0.68)\,(1030) \;=\; 700 \text{ APHA units}$$

D. Ammonia Nitrogen Removal

$$@X_vT \;=\; 1615 \quad N_e/N_o \;=\; 0.255 \text{ (See Figure XVI)}$$
$$N_e \;=\; (0.255)\,(15) \;=\; 3.8 \text{ mg/l}$$

E. Effluent Suspended Solids

Solids loading = (2950)(0.25 + 0.17) (8.34)
= 16,965 pounds/day
Effluent biological solids = 670 pounds/day
(See Figure XVII) = 155 mg/l

Total solids = Influent plus biological solids
= 175 + 155 = 330 mg/l

## TABLE XXIV PROCESS DESIGN CALCULATIONS FOR CONTAMINANT REMOVAL (CONT'D)

F. Cooling

Hours of aeration = 15.5
Temperature change = 10°C (See Figure XIV)
Effluent temperature - influent - change =
35-10 = 25°C

Alum Coagulation Process (see Section IX for development of relationships)

A. BOD Removal

Influent BOD = 85 mg/l
$(S_o - S_e)$/Alum = 0.205 (See Figure XXX)
$(87 - S_e)/300 = 0.205$
$S_e = 25$ mg/l

B. COD Removal

Influent COD = 968 mg/l
$(S_o - S_e)$/Alum = 1.95 (See Figure XXXI)
$(968 - S_e)/300 = 1.95$
$S_e = 380$ mg/l

C. Color Removal

At pH = 6.5
Influent color = 700 APHA
$(C_o - C_e)$/Alum = 1.35 (See Figure XXXII)
$(700 = C_e)/300 = 1.35$
$C_e = 295$ APHA units

At pH = 5.0
$C_e' = 0.65\ (C_e)$
(See Figure XXXIII)
$C_e' = 190$ APHA units

D. Orthophosphate Removal

Removal rate = 0.14 gr/gr Alum
Effluent phosphate = Influent - (0.14) (Alum dose)
= 60 - (0.14) (300)
= 18 mg/l as $PO_4$

E. Clarifier Performance

Influent solids = (330) (0.52) (8.34)
= 1430 pounds/day
Effluent solids = 390 pounds/day (See Figure XXXIV)
= 90 mg/l

# TABLE XXV

## PROCESS DESIGN CALCULATIONS
## FOR SLUDGE PRODUCTION

Excess Activated Sludge (see Section VIII for development of relationships)

$$\frac{X_a}{VX_vT} = \frac{A'(S_o - S_e)}{X_vT} + B'$$

$$\frac{X_a}{(2500)(8.34)(.336)} = \frac{0.625\ (450-87)\ (24)\ (8.34)}{(2500)\ (8.34)\ (15.5)} - 0.012$$

$$X_a = (0.140 - 0.012)\ (7006)$$

Total Solids Generated =

$X_a$ = 897 pounds/day = 407 kilograms/day

Solids Loss in Effluent = (155)(8.34)(.52)
= 672 pounds/day = 305 kilograms/day

Solids to Centrifuge = 897 - 672
= 225 pounds/day = 102 kilograms/day

Flow = $(225)(10^6)/(8.34)(10,000)$
= 2700 gallons/day = 10.2 cubic meters/day

Alum Coagulation Sludge (see Section IX for development of relationships)

Influent Solids Plus Alum Dose
= (330 + 300) (8.34) (.52)
= 2732 pounds/day = 1240 kilograms/day

Effluent Solids Plus Waste Solids (See Figure XXXV)
= (0.67)
= 1830 pounds/day = 831 kilograms/day

## TABLE XXV PROCESS DESIGN CALCULATION FOR SLUDGE PRODUCTION (CONT'D)

Effluent Solids = (90) (8.34) (.52) (see Figure XXXIV)
= 390 pounds/day = 177 kilograms/day

Solids to Centrifuge = total waste - effluent solids
= 1830 - 390
= 1440 pounds/day = 654 kilograms/day

Sludge Flow = (1440) ($10^6$)/(8.34)(20,000)
= 8600 gallons/day = 32.6 cubic meters/day

# TABLE XXVI

## PROCESS DESIGN CALCULATIONS
## FOR OPERATING CHARACTERISTICS

Oxygen Consumption (see Section VIII for development of relationships)

$$R/X_v = A\ (S_o - S_e)/X_vT + B$$

$$R/(2500)\ (8.34)\ (.52) = \frac{0.64\ (450 - 87)\ (24)\ (8.34)}{(2500)\ (8.34)\ (15.5)} + 0.13$$

$$R = (0.143 + 0.13)\ (7006)$$

$$R = 1913 \text{ pounds/day} = 80 \text{ pounds/hr} = 36.3 \text{ kilograms/hour}$$

Chemical Usage (see Sections VIII and IX)

| | Dose | | Use | |
|---|---|---|---|---|
| | (mg/l) | (pounds/ton) | (pounds/day) | (Kg/day) |
| Alum | 300 | - | 1300 | 590 |
| Caustic soda | 50 | - | 217 | 98 |
| Coagulation polymer | 4.0 | - | 17 | 7.8 |
| Centrifuge polymer | | | | |
| - Biological | - | 5 | 0.6 | 0.3 |
| - Chemical | - | 20 | 14 | 6.5 |
| Defoamer | 25 | - | 108 | 49 |
| Hydrogen Peroxide | | | | |
| - Equal. tank | 25 | - | 108 | 49 |
| - Chem. clarifier | 10 | - | 43 | 20 |

# TABLE XXVII

## TREATMENT PROCESS MATERIAL BALANCE

| CONTAMINANT | EQUALIZED WASTE | ACTIVATED SLUDGE | ALUM COAGULATION | SLUDGE |  | CENTRATE | SLUDGE CAKE |
|---|---|---|---|---|---|---|---|
|  |  |  |  | EXCESS ACTIVATED | ALUM |  |  |
| VOLUME | 0.520 (a) | 0.520 (a) | 0.520 (a) | 0.0027 (a) | 0.0086 (a) | 0.010 (a) | 4.60 (b) |
| TEMPERATURE (°C) | 35 | 25 | 25 | - | - | - | - |
| PH | 6.7 | 6.7 | 6.5 | - | - | 7.3 | - |
| DISSOLVED OXYGEN (MG/L) | 2.0 | 1.5 | 2.0 | - | - | - | - |
| BOD (MG/L) | 450 | 87 | 25 | - | - | - | - |
| COD (MG/L) | 1550 | 968 | 380 | - | - | 750 | - |
| COLOR (APHA) | 1030 | 700 | 295 | - | - | 250 | - |
| SUSPENDED SOLIDS (MG/L) | 175 | 330 | 90 | 10,000 | 20,000 | 200 | 14 (c) |
| DISSOLVED SOLIDS (MG/L) | 715 | 620 | 600 | - | - | 600 | - |
| AMMONIA NITROGEN (MG/L) | 15.0 | 3.8 | 2.8 | - | - | 35.0 | 10 (d) |
| ORTHOPHOSPHATE (MG/L) | 60.0 | 60.0 | 18.0 | - | - | 10.0 | 100 (d) |
| ALUMINUM (MG/L) | 8.5 | 8.5 | 10 | - | - | - | 155 (d) |
| CHROMIUM (MG/L) | 0.60 | 0.37 | 0.20 | - | - | - | 0.9 (d) |
| COPPER (MG/L) | 0.03 | 0.03 | N.D. | - | - | - | 0.04 (d) |
| IRON (MG/L) | 0.40 | 0.50 | 0.60 | - | - | - | 5.0 (d) |
| MERCURY (MG/L) | 0.0015 | 0.0017 | 0.0016 | - | - | - | 0.002 (d) |
| ZINC (MG/L) | 0.13 | 0.22 | 0.11 | - | - | - | 0.30 (d) |
| PHENOL (MG/L) | 0.10 | 0.025 | 0.03 | - | - | - | - |
| SULFATE (MG/L) | 150 | 135 | 265 | - | - | - | - |
| ALKALINITY (MG/L) | 105 | 65 | 30 | - | - | - | - |

NOTES

(a) MGD (3785 CUBIC METERS/DAY)
(b) TONS WET SLUDGE/DAY
(c) PERCENT
(d) MG/GR

# SECTION XI

# SLUDGE HANDLING

## PART A - CHEMICAL AND BIOLOGICAL ANALYSIS

A number of tests were made during the course of the study to determine the chemical characteristics of the waste sludge produced by the treatment system. Table XXVIII presents the results of several separate analyses that were made of the combined biological and chemical sludges. These analyses indicate that a significant part of the sludge was inorganic chemicals such as aluminum, iron, chromium, zinc, lead, phosphate, sulfate, and chloride salts. Ammonia nitrogen and COD were also present in a significant concentration indicating that organic material was a major constituent of the sludge. It should be noted, in considering the wastewater removal values for iron, mercury, phosphate, ammonia nitrogen, and aluminum, the concentration values reported for the sludge are higher than anticipated.

The ultimate disposal route for the dewatered sludge from the BRW treatment plant will be by landfilling. In order to determine the possible constituents in the leachate at the landfill site, a laboratory study was conducted. In the study a four-inch (10.1 centimeter) diameter column was packed with five inches (12.7 centimeter) of dewatered sludge on top of a two-inch (5.1 centimeter) layer of sand and gravel. Distilled water was then applied continuously to the surface of the packed sludge at the rate of 220 milliliters per day. The leachate was collected and analyzed periodically. A summary of the results of the chemical analyses are presented in Table XXIX. The BOD, COD, and total solids data indicate that there was substantial leaching of organic and inorganic material during the first ten days following application of water, and after one month these values had stabalized. The iron content in the leachate remained constant over the test period. The chromium content in the leachate was low in comparison with the cake content indicating the chromium was not readily leached. In comparison, the copper

# TABLE XXVIII

## CHEMICAL ANALYSIS OF WASTE SLUDGE

| | SLUDGE SLURRY (MG/L) | LAB SLUDGE CAKE (MG/G) | LAB SLUDGE CAKE (MG/G) | CENTRIFUGE SLUDGE CAKE (MG/G) |
|---|---|---|---|---|
| IRON | - | 1.46 | 8.04 | 5.20 |
| TOTAL CHROMIUM | 14.0 | 1.406 | 0.796 | 0.55 |
| HEXAVALENT CHROMIUM | - | - | 0 | 0.025 |
| COPPER | 0.62 | 0.040 | 0.042 | 0.027 |
| NICKEL | 0.12 | 0.008 | 0.048 | N.D. |
| LEAD | 1.11 | 0.036 | 0.145 | 0.30 |
| CADMIUM | N.D. | 0.0022 | N.D. | 0.008 |
| MANGANESE | - | 0.040 | - | - |
| ZINC | 1.98 | 0.136 | 0.304 | 0.41 |
| ARSENIC | 0.155 | 0.0015 | - | - |
| CALCIUM | - | 3.20 | - | - |
| ALUMINUM | - | 200 | 100 | 166 |
| SODIUM | - | 2.2 | - | - |
| POTASSIUM | - | 2.9 | - | - |
| MERCURY | 0.008 | 0.0052 | 0.0002 | 0.0010 |
| BERYLLIUM | 0.025 | - | - | - |
| SELENIUM | 0.035 | N.D. | - | - |
| PHOSPHATE (AS P) | 6.7 | 1.07 | 0 | 900 |
| SULFATE | 520 | 520 | 1.04 | 6.0 |
| CHLORIDE | - | 9.6 | 0 | 47.5 |
| AMMONIA NITROGEN | - | 10.0 | - | - |
| CYANIDE | - | N.D. | 0 | N.D. |
| PESTICIDES | NEGATIVE | - | 0 | 16.80 |
| CHLOROFORM EXTRACTABLES | NEGATIVE | - | 0 | NEGATIVE |
| ACID INSOLUBLES | - | 445 | - | - |
| TOTAL SOLIDS | 19,950 | - | 0 | - |
| TOTAL SUSPENDED SOLIDS | 18,900 | - | 0 | - |
| PHENOL | - | - | 0 | 0.0049 |
| COD | 26,760 | - | - | - |
| ALKALINITY | 430 | - | - | - |
| ACIDITY | 230 | - | - | - |

# TABLE XXIX

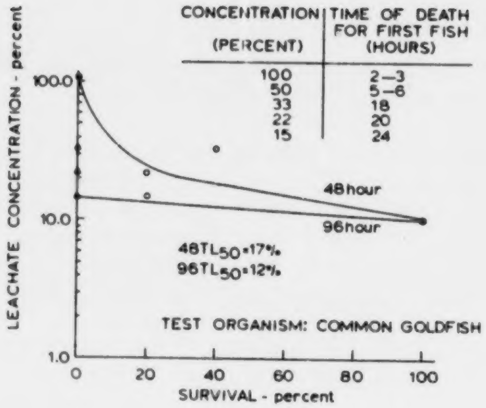
## SLUDGE LEACHATE CHARACTERISTICS

| CONTAMINANT | TIME FROM START OF STUDY<br>TWO DAYS | FIVE DAYS | TEN DAYS | TWENTY-NINE DAYS | SIX MONTHS |
|---|---|---|---|---|---|
| PH | 7.3 | 7.3 | 7.3 | 6.9 | 7.0 |
| BOD (MG/L) | 252 | 402 | 480 | 240 | 141 |
| COD (MG/L) | 1027 | 1244 | 1170 | 531 | 504 |
| TOTAL SOLIDS (MG/L) | 1128 | 1130 | 784 | 322 | 484 |
| TSS (MG/L) | 56 | 80 | - | 60 | 83 |
| IRON (MG/L) | 1.39 | 2.45 | 2.53 | 2.35 | 2.48 |
| CHROMIUM (MG/L) | 0.05 | 0.035 | 0.08 | N.D. | - |
| TOTAL COPPER (MG/L) | 0.26 | 0.21 | N.D. | N.D. | 0.12 |
| SOLUBLE COPPER (MG/L) | - | - | - | - | 0.02 |
| LEAD (MG/L) | 0.06 | 0.04 | 0.06 | 0.06 | N.D. |
| TOTAL ZINC (MG/L) | 0.38 | 0.23 | 0.11 | 0.14 | 0.18 |
| SOLUBLE ZINC (MG/L) | - | - | - | - | 0.05 |
| TOTAL ALUMINUM (MG/L) | 0.06 | 0.4 | - | 1.0 | 0.50 |
| SOLUBLE ALUMINUM (MG/L) | - | - | - | - | 0.12 |
| CALCIUM (MG/L) | 32 | - | 19 | 11 | - |
| COLOR (APHA) | COMPOSITE = 400 | | | | 250 |

in the cake was leached in the first five days. Zinc which was present was readily leached in the first five days, and then remained at a constant low level. The aluminum content in the leachate was suprisingly low considering that twenty percent by weight of the sludge cake was aluminum. Color in the leachate was relatively constant for the first 30 days but slowly reduced with time.

Static bioassays using the leachate were also conducted to determine relative toxicity. Common gold fish was the test organism. The results of the test are presented in Figures XLIV and XLV and indicate a 96 hour $TL_{50}$ of 12.0 percent after 30 days and 25.0 percent after 6 months of leaching.

During a portion of the study, waste wet sludge from the treatment system was sent to the ocean for disposal. As part of the US EPA permit program for ocean disposal, a static bioassay of the wet sludge was run using brine shrimp, Artemia Salina, as the test organism. Figure XLVI illustrates the results of this test, and indicates a 96 hour $TL_{50}$ of 2.7 percent.



| CONCENTRATION (PERCENT) | TIME OF DEATH FOR FIRST FISH (HOURS) |
|---|---|
| 100 | 2–3 |
| 50 | 5–6 |
| 33 | 18 |
| 22 | 20 |
| 15 | 24 |

FIGURE XLIV. Survival curve for one month leachate

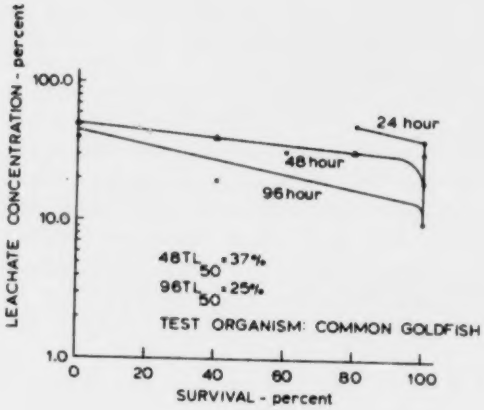


FIGURE XLV. Survival curve for six month leachate

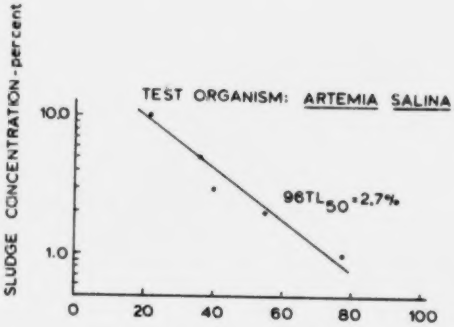


FIGURE XLVI. Survival curve for wet sludge

## PART B - VACUUM FILTER OPERATION

Because of the poor performance of the original pre-coat vacuum filter system in handling the treatment plant sludge, very little data was gathered to define its operating characteristics during the grant period. The information that was obtained is summarized in Table XXX.

The primary reason for the filter system not performing satisfactorily was the extended periods of down-time between filter runs. Typically approximately one shift was required to wash down the filter and apply a new four inch pre-coat layer. However, it was seldom possible to begin the pre-coat operation immediately after the filter shutdown, so that the average downtime between runs was approximately twenty-four hours. As a result, solids accumulated in the storage tank prior to the filter and an anaeraobic condition quickly developed. The partially digested sludge was extremely difficult to dewater because of the tendency to blind to filter surface. The storage problem was compounded by a sludge flow rate that exceeded the design expectations and resulted in increased retention time in the storage tank.

A review of these operational problems shortly after the treatment system was functional determined that vacuum filtration was not a feasible method of dewatering.

## TABLE XXX

## SUMMARY OF VACUUM FILTER PERFORMANCE

| | |
|---|---|
| SOLIDS FEED TO STORAGE TANK | 4,100 MG/L |
| SOLIDS FEED TO FILTER FROM STORAGE | 23,600 MG/L |
| TOTAL FEED RATE | 30 GALLONS (0.11 CUBIC METERS) PER MINUTE |
| RECYCLE RATE | 15 GALLONS (0.05 CUBIC METERS) PER MINUTE |
| CAKE MOISTURE (INCLUDES PRE-COAT) | 65 PERCENT |
| FILTER RUN TIME | 60 HOURS |
| TIME TO PRE-COAT | 8 HOURS |
| TOTAL DOWN TIME | 24 HOURS |
| PRE-COAT TYPE | DICALITE 436 |
| PRE-COAT USE PER FILTER RUN | 900 POUNDS (409 KILOGRAMS) |
| FILTER BACK | COTTON CLOTH |

## PART C - CENTRIFUGE OPERATION

Prior to the purchase of full-scale centrifuge equipment for sludge dewatering, performance evaluation testing was conducted using pilot-scale equipment at the customer demonstration laboratory of Sharples Centrifuge Division of the Pennwalt Corp. Both solid bowl (basket) and horizontal scroll units were evaluated using a combined biological and chemical sludge.

The solid bowl unit was able to produce a sludge cake of 11 percent solids without a polymer but with only a 85 percent solids recovery.

The horizontal scroll unit was able to produce a sludge cake of 15 percent solids with over 95 percent solids recovery. The performance of this unit was found to be dependent on polymer dose and differential conveyor speed, and the requirements for each of these operational characteristics was found to vary widely between sludge samples. It was estimated that considerable flexibility was required in order to handle the various sludges from the treatment system and that the horizontal scroll type provided this flexability. It was projected that the model selected would handle 35 gallons (0.13 cubic meters) per minute of a two percent sludge at a polymer dose of 10-20 pounds/ton (0.005 gr/kilogram) and with a 95 percent solids recovery. Typical test data from the horizontal scroll trial is presented in Figure XLVII.

The full-scale horizontal scroll centrifuge was placed in operation at BRW in March, 1974. Table XXXI presents a summary of the operating characteristics of this unit, and although the data used was gathered after the end of the base study period, the sludge characteristics experienced were felt to be similar to those previously reported. Excess activated sludge was found to dewater very easily upon centrifugation with only a low polymer dose required for good solids recovery and cake dryness. Alum sludge was found to dewater to a sufficient cake dryness only at a higher polymer dose. Initially the sludges were dewatered together but it was determined that the operators could better control the centrifuge's performance if the sludges were dewatered separately. Although the cake dryness indicated by the data for activated sludge is lower than for alum sludge, both sludges had the same consistency ("truckable") and performance was determined to be satisfactory in both cases.

The centrate from the unit was returned to the flocculation basin, and Table XXXII presents a summary of the chemical characteristics of the centrate. For the excess activated sludge, the centrate was found to be similar to the activated sludge clarifier overflow except for a much lower color value. For the alum sludge the high polymer dose (using a polyamine cationic polymer) significantly increased the centrate COD and ammonia nitrogen values. Grab samples of centrate were used in these evaluations.

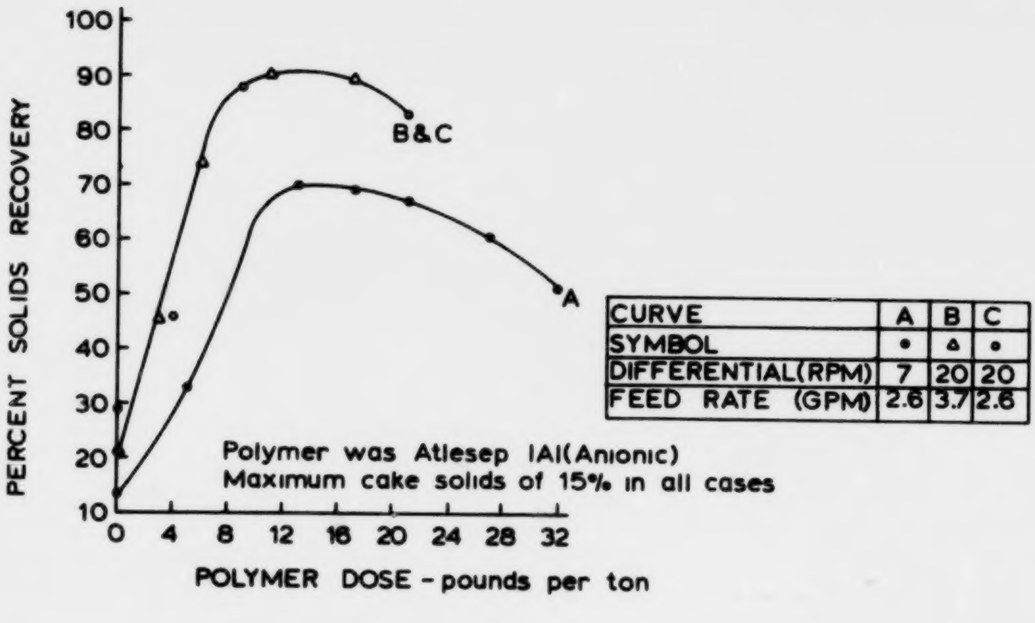


FIGURE XLVII. Solids recovery in pilot centrifuge

# TABLE XXXI

## SUMMARY OF CENTRIFUGE PERFORMANCE

| PARAMETER | EXCESS ACTIVATED SLUDGE | ALUM SLUDGE | COMBINED SLUDGE |
|---|---|---|---|
| FEED RATE (GPM) | 7.6 | 16.4 | 11.0 |
| FEED SOLIDS (PERCENT) | 1.74 | 1.95 | 1.42 |
| SOLIDS RECOVERY (PERCENT) | 95 | 99 | 98 |
| CAKE SOLIDS (PERCENT) | 10.5 | 15.7 | 13.6 |
| DIFFERENTIAL SPEED (RPM) | 12 | 10 | 16 |
| POND SETTING | 3.5 | 3.5 | 3.5 |

# TABLE XXXII

## SUMMARY OF CENTRATE CHARACTERISTICS

| CHARACTERISTIC | EXCESS ACTIVATED SLUDGE CENTRATE | ALUM COAGULATION SLUDGE CENTRATE |
|---|---|---|
| PH | 7.1 | 7.5 |
| TOTAL SUSPENDED SOLIDS (MG/L) | 68 | 91 |
| TOTAL DISSOLVED SOLIDS (MG/L) | 450 | 640 |
| COLOR (APHA) | 180 | 260 |
| AMMONIA NITROGEN (MG/L AS N) | 15 | 46 |
| ORTHOPHOSPHATE (MG/L AS $PO_4$) | 20 | 5 |
| COD (MG/L) | 485 | 940 |

# SECTION XII

# SUMMARY OF COST INFORMATION

Capital and operating cost data for the treatment system is summarized in Tables XXXIII and XXXIV. To develop the actual unit costs indicated, the total water volume processed - 163,050,000 gallons (617,144 cubic meters) - and the total goods produced - 13,523,774 pounds (6,139,793 kilograms) - during the study year were used. To develop the design unit costs indicated, a water volume of 360 million (1.36 million cubic meters) gallons and a production level of 30 million pounds (13.62 million kilograms) were used.

The capital expenditure required to build a combined activated sludge, alum coagulation system for a yearly wastewater volume of 360 million gallons (13.62 million cubic meters) was estimated at $1,150,000 or $3.19 per thousand gallons ($0.84 per cubic meter) of design capacity. Based on the projected profit level for the 30 million pounds (13.62 million kilograms) of product per year generating this wastewater volume, the capital expenditure would be approximately 20 percent of net yearly profit. The operating cost for the treatment system was estimated at $430,420 per year. The unit costs were estimated to be $1.20 per design thousand gallons treated ($0.32 per cubic meter), $0.014 per design pound of product ($0.031 per kilogram), and 8 percent of yearly net profit at the design production level. All costs are in 1973 dollars.

The labor costs indicated for the actual grant period include 3.5 operators, 1 superintendent/chemist, and 1 part-time technician. The projected labor cost include 4 operators, 1 superintendent, 1 chemist, and 1 full-time technician.

# TABLE XXXIII

## SUMMARY OF COST INFORMATION

### CAPITAL COST

| | |
|---|---|
| ACTUAL COST FOR INITIAL TREATMENT PLANT AND MODIFICATIONS | $1,328,000 |
| ESTIMATED COST FOR SINGLE PHASE CONSTRUCTION | |
| - TOTAL | $1,150,000 |
| - PER ACTUAL THOUSAND GALLONS PER YEAR | $7.05 |
| - PER DESIGN THOUSAND GALLONS TREATED PER YEAR | $3.19 |
| - PER DESIGN CUBIC METERS TREATED PER YEAR | $0.84 |

### OPERATING COST

| | ACTUAL | ESTIMATED FOR DESIGN VOLUME AND SINGLE PHASE CONSTRUCTION |
|---|---|---|
| DEPRECIATION | $88,530 | $76,670 |
| OPERATING LABOR | 50,310 | 58,450 |
| SUPPLIES | 38,880 | 137,000 |
| SLUDGE DISPOSAL | 25,000 | 52,500 |
| UTILITIES | 10,310 | 15,000 |
| REPAIRS | 13,770 | 11,500 |
| LABORATORY | 11,400 | 32,000 |
| INDIRECTS | 30,830 | 47,300 |
| TOTAL | $269,030 | $430,420 |

## TABLE XXXIII SUMMARY OF COST INFORMATION (CONT'D)

| | ACTUAL | ESTIMATED FOR DESIGN VOLUME AND SINGLE PHASE CONSTRUCTION |
|---|---|---|
| - PER THOUSAND GALLONS TREATED PER YEAR | $1.65 | $1.20 |
| - PER CUBIC METER TREATED PER YEAR | $0.43 | $0.32 |
| - PER POUND OF PRODUCT PER YEAR | $0.020 | $0.014 |
| - PER KILOGRAM OF PRODUCT PER YEAR | $0.043 | $0.031 |

# TABLE XXXIV

## BASIS OF ESTIMATED OPERATING COST FOR DESIGN TREATMENT LEVEL

### CHEMICALS

| | COST (DRY BASIS) | | USE |
|---|---|---|---|
| | PER POUND | PER KILOGRAM | |
| ALUM | $0.036 | $0.079 | 275 MG/L |
| CAUSTIC | 0.217 | 0.478 | 40 MG/L |
| ANIONIC POLYMER | 1.617 | 3.562 | 5 MG/L |
| CATIONIC POLYMER | 1.930 | 4.251 | 20 POUNDS/TON (10 KG/KKG) |
| DEFOAMER | 0.526 | 1.158 | 20 MG/L |
| HYDROGEN PEROXIDE | 0.411 | 0.905 | 35 MG/L |

### UTILITIES

| | |
|---|---|
| WATER | $0.29/1000 GALLONS ($0.08/CUBIC METER) |
| POWER | $0.01/KWH |

### LABOR

| | |
|---|---|
| OPERATORS (4) | $4.25/HOUR |
| SUPERINTENDENT | $6.00/HOUR |
| CHEMIST | $5.25/HOUR |
| LAB TECHNICIAN | $4.00/HOUR |
| INDIRECT (FRINGE BENEFITS, MANAGEMENT, SECRETARY, SAFETY, ETC.) | 55% OF LABOR |

### MAINTENANCE AND REPAIRS

| | |
|---|---|
| MATERIAL AND LABOR | 1% OF CAPITAL COST |

### SLUDGE DISPOSAL

| | |
|---|---|
| HAULING AND BURIAL | $15.00 PER CUBIC YARD ($19.4 PER CUBIC METER) |

# SECTION XIII

# OPERATIONAL AND MECHANICAL DIFFICULTIES

## PART A - OPERATIONAL

One of the more troublesome problems encountered with the treatment system was odor generation. Since the system was located in a residential neighborhood, any odors were immediately detected and resulted in numerous complaints. The septic odor problems in the equalization tank and chemical clarifier have been mentioned previously and were found to be controllable by the use of hydrogen peroxide. However, a "chemical" odor was found to persist at the aeration lagoon, and a sampling program was instituted to define this problem. A small vacuum pump was used to pull a 2.0 liter per minute ambient air sample through a carbon tube. The sampling apparatus was suspended on the aerator access bridge two feet (0.6 meters) above the lagoon surface.

Each carbon tube was desorbed with carbon disulfide for 24 hours. The resulting samples were injected into a gas chromatographic column at 150°C and detected using flame ionization . The aromatic chemicals, toluene and xylene, were found to compromise 50 percent of the hydrocarbon emission with the balance being five or six hydrocarbons in the $C_8$ to $C_{10}$ range. Total hydrocarbon concentrations ranged from 0.378 mg/cubic meter to 1.60 mg/cubic meter with an average of 1.12 mg/cubic meter. The data collected is presented in Table XXXV. The presence of these chemicals in the ambient air at the lagoon was thought to be due to air stripping as a result of the severe agitation of the mixed liquor by the aeration device.

As previously mentioned in Section VIII, foaming in the aeration basin was a continual problem during the study period. Immediately after the system was put into operation, a foam baffle was erected around the aeration lagoon parameter to prevent solids loss by foaming. Several attempts were made at defoamer addition. A system of metering the defoamer into a dilution water line and the spraying of the dilute defoamer water on the lagoon surface was found to be the most effective method of preventing excess foam build-up in the lagoon. The most successful change that effectively reduced the foam to a level requiring only periodic defoamer use, was a lowering of the water level in the lagoon. A new outlet structure resulted in a drop of submergence of the aerator (measured when the aerator unit was not operating) from five inches (12.7 cm) to three inches (7.6 cm).

# TABLE XXXV

## ANALYSIS OF AMBIENT AIR AT THE AERATION LAGOON SURFACE

**SAMPLE #1**

TOTAL HYDROCARBON 1.43 MG/M$^3$

1.0 µG TOLUENE
24 µG XYLENE
60 µG $C_8$ - $C_{10}$ HYDROCARBONS

**SAMPLE #2**

TOTAL HYDROCARBONS 1.10 MG/M$^3$

2.2 µG TOLUENE
30 µG XYLENE
100 µG $C_8$ - $C_{10}$ HYDROCARBONS

**SAMPLE #3**

TOTAL HYDROCARBONS 1.60 MG/M$^3$

4.0 µG TOLUENE
60 µG XYLENE
320 µG $C_8$ - $C_{10}$ HYDROCARBONS

**SAMPLE #4**

TOTAL HYDROCARBONS 1.14 MG/M$^3$

2.4 µG TOLUENE
36 µG XYLENE
30 µG $C_8$ - $C_{10}$ HYDROCARBONS

**SAMPLE #5**

TOTAL HYDROCARBONS 1.05 MG/M$^3$

3.0 µG TOLUENE
44 µG XYLENE
80 µG $C_8$ - $C_{10}$ HYDROCARBONS

**SAMPLE #6**

TOTAL HYDROCARBON 0.378 MG/M$^3$

2.8 µG TOLUENE
38 µG XYLENE
50 µG $C_8$ - $C_{10}$ HYDROCARBONS

Foam in the final effluent continued to persist throughout the study and was particularly severe when the effluent pH dropped below 5.5 as a result of a problem with the neutralization system. The tendency to foam was apparent even during periods of extremely high performance, and as indicated in Section X, this foaming was apparently due to surface active chemicals not measured by the Standard Methods test for anionic detergents(15). A significant reduction of this foaming tendency was found to be provided only by a tertiary adsorption process.

As previously described in Section VIII, sludge was returned from the activated sludge clarifier to the lagoon at a constant rate and there was no instrumentation available to indicate or regulate this rate. Similarly, there was no instrumentation available for either the alum or activated sludge waste lines to indicate or regulate flow rate, and flows were estimated from pump performance curves and checked crudely with a bucket and stop watch. As a result, the activated sludge system could not be tightly regulated and controlled by determination of optimum return and waste rates, and the sludge production rates for both the activated sludge and alum process may not be as accurate as desirable.

The rapid mix, flocculation, and polymer feed equipment described in Section IX was not placed in service until late in the study period. The major benefit from the installation of this equipment was the reduction in alum sludge volume which, considering the capital and operating cost of sludge dewatering and disposal, was of major significance. A corollary benefit was that the alum sludge settled with zone settling rather than discrete settling characteristics with the result that it was much easier for the operators to control solids loss from the clarifier.

A number of sources in the literature report on the mixing requirements for rapid mixing and flocculation using the mean velocity gradient, $\bar{G}$, as the measure of mixing required. For rapid mixing values of over 300 $sec^{-1}$ are reported(15) and for flocculation values of 30-100 $sec^{-1}$ are reported (5,11,13). For the BRW system, the $\bar{G}$ values for the rapid mix and flocculation basins were 200 $sec^{-1}$ and 35 $sec^{-1}$ respectively.

The alum coagulation clarifier was not designed as a "reactor clarifier" or "sludge blanket" clarifier. That is, the center baffle of the unit extended below the water surface only one-third of the total water depth. In "sludge blanket" clarifiers, this baffle typically extends to two-thirds or three-quarters of the total depth so that a solid layer of a depth higher than the bottom of the baffle results in a feedwater flow through the settled solids. This flow pattern typically results in better solids removal by contacting the freshly generated solids with settled sludge to increase floc size and floc density. The alum sludge generated at BRW was felt to be amenable to this sedimentation process. However, because of the fragile nature of the floc, a "solids recirculating" clarifier would not be applicable to the alum coagulation process.

In flowing from the flocculation basin to the clarifier there was an apparent breaking of some of the floc. Experiments in the laboratory attempted to duplicate this situation and indicated that the fine solids resulting from this turbulence would not readily flocculate again without the addition of more polymer. It was felt that the addition of a small concentration of polymer into the center baffle of the clarifier would aid in capturing a significant portion of effluent suspended solids which result from floc breakage during transport.

## PART B - MECHANICAL

The major mechanical difficulty experienced with the treatment system was the lack of back-up equipment to prevent degradation of performance in the event of equipment failure. This was particularly true in the case of chemical metering pumps. A major modification program underway at BRW will result in the duplication of all major process equipment (except tankage) and this policy of installed spare equipment has already demonstrated its usefulness.

The metering pumps used in the treatment system came equipped with a calibrated stroke adjustment. Daily dosages were calculated based on a single calibration curve obtained when the system was first placed in operation. Recently these pumps were replaced and the new feed systems now include in-line graduated cylinders for calibration. Weekly checks on calibration has indicated a significant variation as a result of changing chemical storage tank or treatment vessel liquid level.

Liquid caustic soda was chosen for pH adjustment rather than lime because of anticipated ease of operation and lower control cost. However, because of the high crystallization point of 50 percent caustic soda (approximately 7°C) numerous problems were encountered with plugging of feed lines. It was very apparent that in designing a caustic system extreme care must be exercised to insure that all caustic lines, tanks, and pumps, are properly heated and insulated and that as much of the equipment as possible is located indoors.

The gravity flow line between the aeration lagoon and activated sludge clarifier in the initial treatment plant was sized for a maximum flow of 400 gallons (1.5 cubic meters) per minute and any flow in excess of this value caused a rise in the water level of the lagoon and a consequent strain on the aerator electrical componets. To overcome this problem, a new line was installed, but because of mechanical restraints, this line discharged at the clarifier surface just outside the center baffle. This arrangement allowed for a higher flow but also resulted in a point loading of solids in the clarifier. Late in the study, the center baffle was enlarged, and near normal inlet distribution of solids were restored.

One of the most important concepts in the design of a treatment plant, is the allowance for flexibility of operation under varying load and treatability conditions. Unfortunately the initial design of the BRW treatment plant did not include a reasonable allowance for changes in process characteristics such as flow or chemical dosage or for mechanical problems such as pump failure. This lack of flexibility was undoubtedly reflected in the total performance characteristics of the system, and the selective data evaluation attempted to remove periods of mechanically caused low performance from the analysis of system capability.

# SECTION XIV

# ANALYSES OF PRODUCTION CHEMICALS AND PROCESSES

## PART A - CHARACTERIZATION OF PRODUCTION CHEMICALS, DYES AND FABRICS

As indicated in Section IV, the manufacturing operation at BRW involved the use of a wide variety of chemicals, dyes, and fabrics in a constantly changing product mix. Several studies were undertaken in an attempt to develop an environmental characterization of the production processes. The first of these studies to be reviewed in this section involved the characterization of chemicals, dyes, and fabrics.

Tables XXXVI through XXXVIII present total and soluble COD data for major dyes, chemicals, and fabric as they are received at BRW (soluble indicates material passing Whatman number 5 filter paper). A wide variation was obtained in repetitive samples for the fabric COD values, and, as a result, the data presented be useful only for a qualitative analysis.

Not all of the COD indicated by these tests is discharged to the sewer system since there may be some loss of the chemical to the atmosphere or some retention on the fabric. Several analyses were attempted to determine the portion of major chemicals entering the sewer system and the portion retained on the fabric or lost to the atmosphere, but no meaningful data was obtained because of the wide variation in the results of repetitive analyses.

A number of dyes were analyzed for color values at various concentrations using the APHA method on un-filtered, un-neutralized solutions, and this data is presented in Figure XLVIII. Considering the nature of the test method, this information can be interpreted only as a method of qualitatively indicating the potentially significant colorants.

## TABLE XXXVI

## CHEMICAL OXYGEN DEMAND OF PRODUCTION CHEMICALS

| CHEMICAL | TOTAL COD | SOLUBLE COD | PERCENT SOLUBLE COD |
|---|---|---|---|
| | (UNIT OF COD/UNIT OF CHEMICAL) | | |
| CARRIER NT | 1.590 | 1.475 | 93 |
| AEROTEX WATER REPELLENT | 0.760 | 0.295 | 39 |
| SOLVECREST RB | 1.430 | 0.460 | 32 |
| CAP LEV ME | 0.930 | 0.390 | 42 |
| OAK SCOUR SO-50 | 2.010 | 0.385 | 19 |
| ACETIC ACID | 0.630 | 0.630 | 100 |
| AVITONE F | 2.730 | 0.920 | 34 |
| ROLLER CLEANER | 1.620 | 0.975 | 40 |
| CAP LUBE LSP | 0.975 | 0.620 | 64 |
| HERRITON SWD | 1.390 | 1.260 | 91 |
| SANDOPAN DTC | 2.790 | 1.280 | 46 |
| CAP CARRIER BB | 1.700 | 0.710 | 42 |
| FORMIC ACID | 0.410 | 0.340 | 83 |
| RACOFIX NY | 0.695 | 0.650 | 94 |
| SOAP OFF 60 | 0.380 | 0.380 | 100 |
| ANTIFUME GFD | 1.800 | 0.800 | 44 |
| OAKAPON X-70 | 1.145 | 1.090 | 95 |
| WINKLER FINISH NO.1 | 0.250 | 0.240 | 96 |
| DISPERSING AGENT | 0.385 | - | - |
| INTRAWITE EBF | 0.245 | 0.185 | 76 |
| RESIN CP | 1.120 | 0.424 | 38 |

## TABLE XXXVII

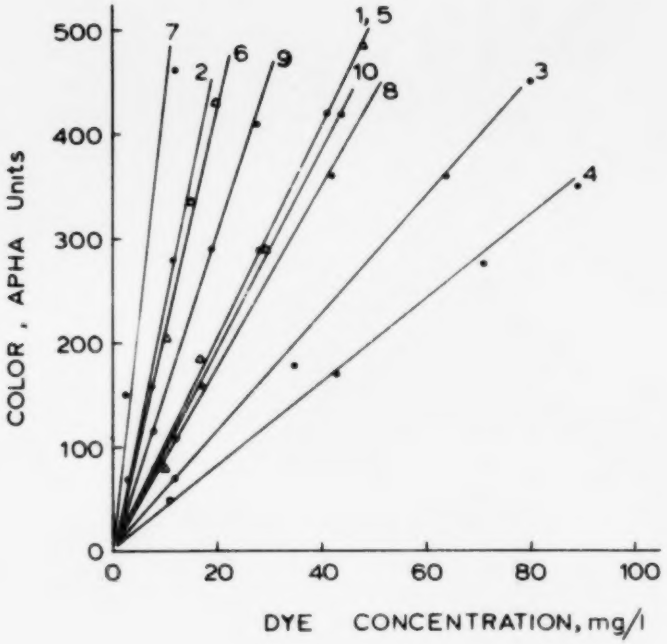
## CHEMICAL OXYGEN DEMAND OF PRODUCTION DYES

| DYESTUFF | TOTAL COD<br>(UNIT OF COD/UNIT OF CHEMICAL) | SOLUBLE COD | PERCENT SOLUBLE COD |
|---|---|---|---|
| EASTMAN BLACK T | 0.685 | 0.365 | 53 |
| LATYL BRILLIANT BLUE BGN | 1.475 | 0.830 | 56 |
| AMACEL BLUE GP | 1.320 | 0.660 | 50 |
| AMACRON BRILLIANT BLUE G | 1.400 | 1.380 | 98 |
| TERASIL NAVY BLUE SGL | 1.210 | 1.075 | 89 |
| INTRALAN BLACK BGL | 1.830 | 0.530 | 29 |
| RESOLIN BRILLIANT YELLOW 76L | 1.405 | 1.375 | 98 |
| CALCOSPERSE RED 5G | 0.870 | 0.699 | 80 |
| ALIZARINE FAST GREEN CGN | 1.510 | 0.655 | 43 |
| CALCOSPERSE BLUE BGLK | 1.005 | 1.005 | 100 |

## TABLE XXXVIII

## CHEMICAL OXYGEN DEMAND FROM VARIOUS FABRIC WASHWATER

| FABRIC | WASH TEMPERATURE (°F) | WATER:FABRIC RATIO (UNIT OF WATER/ UNIT OF CLOTH) | COD (MG/L) | COD (GR) | COD:FABRIC RATIO (UNIT OF COD/ UNIT OF CLOTH) |
|---|---|---|---|---|---|
| 100% ARNEL | 204 | 70:1 | 2550 | 1.34 | 0.134 |
| 100% ARNEL | 240 | 40:1 | 530 | 0.21 | 0.021 |
| 100% NYLON | 208 | 40:1 | 2400 | 1.14 | 0.114 |
| 100% POLYESTER | 208 | 70:1 | 5700 | 2.00 | 0.200 |



| Key Number | Dye |
|---|---|
| 1 | Amacel Blue GP |
| 2 | Eastman Black T |
| 3 | Latyl Brilliant Blue BGN |
| 4 | Amacron Brilliant Blue G |
| 5 | Calcosperse Red 5G |
| 6 | Resolin Brilliant Yellow 76L |
| 7 | Intralan Black BGL |
| 8 | Terasil Navy Blue SGL |
| 9 | Alizarine Green CGN |
| 10 | Foron Yellow - Brown S-2RFL |

**FIGURE XLVIII.** APHA color values for production dyes

A number of reports on textile wastewater treatment that have appeared in the literature have reported the biochemical oxygen demand of production chemicals. Similar work was attempted at BRW, but in all cases there was a non-linear relationship indicated between BOD and chemical concentration. Therefore the test method was determined to be applicable only when a chemical were known to consistently appear at a constant concentration in the wastewater.

An adaptation of the BOD test was used, however, to determine the relative toxicity of a chemical at varying concentrations. In these tests, BOD bottles were prepared using constant concentrations of equalized raw waste to create a decrease in dissolved oxygen. Various concentrations of the chemical were then added to the bottles. An observed decreasing dissolved oxygen depletion with concentration would indicate a retarding of biological activity. A depletion of oxygen less than the depletion caused by the raw waste would indicate toxicity to the seed microorganisms that had been acclimated to the raw waste. A summary of the data obtained is presented in Table XXXIX, and a typical data plot is shown in Figure XLIX. No chemicals or dyes were found which exhibited toxic effects at the concentration expected in the wastewater.

The typical metal content of the classes of dyes used at BRW, as reported by the dyestuff industry, is presented in Table XL.(2)

An analysis of foaming characteristics is presented in Table XLI for various chemicals. Data is reported as foam height, and foam duration. This data indicates that a large number of chemicals used contain surface active chemicals that have a high foaming potential. This Table also lists the percent aromatics and indicates that only three chemicals contain this potentially odorous class of organic chemicals.

# TABLE XXXIX

## SUMMARY OF MULTIPLE DILUTION BOD DATA

| CHEMICAL | CRITICAL CONCENTRATIONS START OF RETARDING (PERCENT) | CRITICAL CONCENTRATIONS START OF TOXICITY (PERCENT) |
|---|---|---|
| CARRIER NT | >10 | >10 |
| AEROTEX WATER REPELLENT | 0.01 | - |
| OAK SCOUR SO-50 | >1.0 | >1.0 |
| AVITONE F | 0.1 | 13 |
| ROLLER CLEANER | >0.02 | >0.02 |
| CAP LUBE LSP | >10 | >10 |
| SANDOPAN DTC | 0.01 | 2.2 |
| RACOFIX NY | NO D. O. DEPLETION DIFFERENT FROM CONTROL | |
| OAKAPON X-70 | >1.0 | >1.0 |
| DISPERSING AGENT | >10 | >10 |
| LYOSEN MS | >10 | >10 |

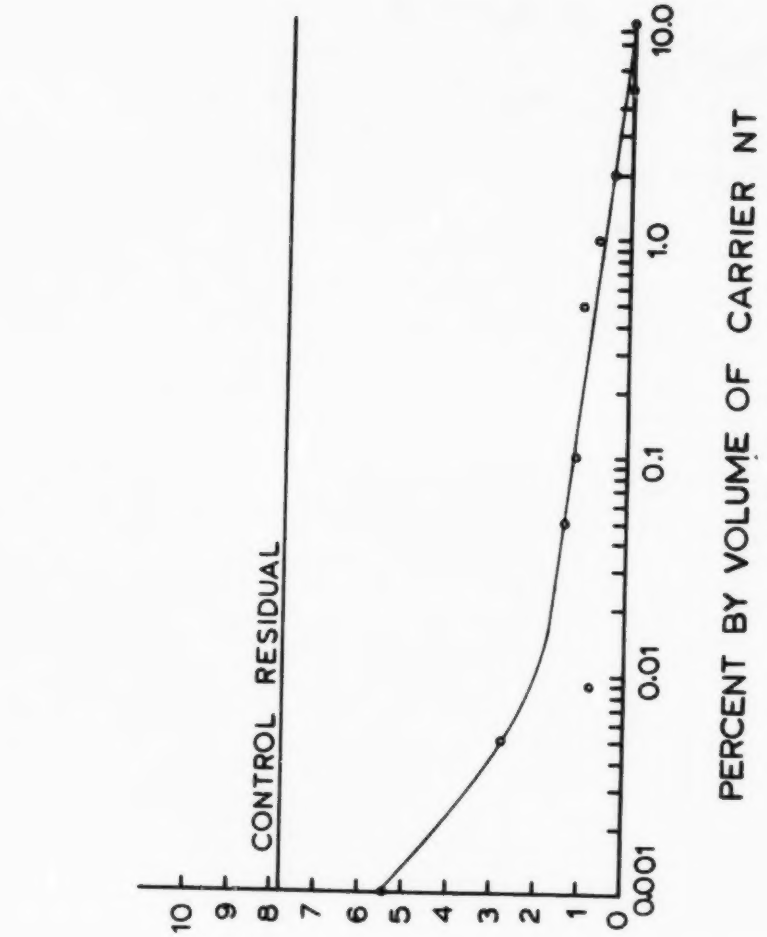


FIGURE XLIX. Multiple dilution BOD data for Carrier NT

# TABLE XL

## AVERAGE METAL CONCENTRATION OF SELECTED DYES

| METAL | AVERAGE METAL CONCENTRATION (MG/L) ACID DYES | AVERAGE METAL CONCENTRATION (MG/L) DISPERSE DYES |
|---|---|---|
| ARSENIC | <1 | <1 |
| CADMIUM | <1 | <1 |
| CHROMIUM | 9.0 | 3.0 |
| COBALT | 3.2 | <1 |
| COPPER | 79 | 45 |
| LEAD | 37 | 37 |
| MERCURY | <1 | <1 |
| ZINC | 13 | 3.0 |

# TABLE XLI

## ANALYSIS OF FOAMING AND ODOR CHARACTERISTICS OF PRODUCTION CHEMICALS

| | PERCENT AROMATICS (PERCENT) | FOAM HEIGHT (INCHES) | TIME FOR FOAM TO DISAPPEAR (MINUTES) |
|---|---|---|---|
| CARRIER NT | 0 | 3.50 | 136 |
| SOLVECREST RB | 0 | 6.00 | 15 |
| CAP LEV ME | 0 | 5.62 | 135 |
| OAK SCOUR 50-50 | 0 | 0.29 | 100 |
| ACETIC ACID | 0 | | |
| MONOSODIUM PHOSPHATE | 0 | | |
| AVITONE F | 0 | 4.40 | ±37.5 |
| CAUSTIC SODA | 0 | - | - |
| CALGON | 0 | 0.02 | 5 |
| NEUTROL #9 | 0 | 6.00 | ±7.5 |
| ROLLER CLEANER | 75 | 0.50 | <1.0 |
| CAP LUBE LSP | 0 | 5.88 | 143 |
| HERRITON SWD | 0 | 1.43 | ±9.5 |
| OAKSPERSE AD-40 | 0 | 0.06 | 90 |
| SANOPAN DTC | 0 | 8.26 | ±11.7 |
| CAP CARRIER BB | 0 | 4.38 | 31 |
| RACOFIX NY | 0 | 4.73 | ±5.2 |
| ANTIFUME GFD | 40 | 2.2 | ±5.3 |
| OAKAPON X-70 | 0 | 19.64 | 240 |
| FANAPON X-70 | 0 | 3.00 | ±5.5 |
| WINKLER FINISH NO. 1 | 0 | 3.19 | ±22.3 |
| OAK LEV NU 9 | 0 | 19.64 | 120 |
| NEOPORT D86 | 80 | 7.25 | ±8.8 |
| LYOGEN P | 0 | 5.7 | ±7.25 |

## PART B - ACTIVATED SLUDGE TREATABILITY STUDIES

A series of tests were performed using production chemicals and dyes to determine treatability characteristics in an activated sludge process. The test method used was to measure COD, oxygen up-take, and mixed liquor solids during a 24 hour batch reactor study. A two-liter graduate cylinder was used as the reactor vessel. Waste was fed to the mixed liquor only at the beginning of the test and mixed liquor solids were used from a batch reactor acclamated to BRW raw wastewater. Table XLII presents a summary of the results of the tests and Figure L illustrates a typical plot of the results.

Only three of the materials tested (Carrier NT, Solvecrest RB, and Avitone F) exhibited a COD removal rate ($S_o$ - $S_e$/XT) within the range determined as typical for the full-scale system. All others exhibited a low or zero rate of degradation at the concentration tested. In all except two cases (Solvecrest RB and Roller Cleaner) the oxygen consumption rate was below that anticipated from the full-scale system (In Figure XVIII of Section VIII, the value of constant B, the oxygen consumption rate due to biological synthesis, was determined to be 0.13 mg/mg-day or 0.005 mg/mg-hr for the full-scale system). A number of the materials (Aerotex and the dyes) exhibited oxygen consumption rates less than this synthesis value with little or no removal of COD, indicating possible retarding or toxic affects. For Aerotex, a retarding effect was also detected for a low concentration (100 mg/l) in the multiple dilution BOD test previously described in Part A of the Section.

The treatability test indicated COD removal due to biological activity and to aeration. If the chemical under study were volatile, an incorrect rate of degradation would be assumed. Several tests were made to determine the loss of COD on aeration without gross biological activity. Results from these tests is presented in Table XLIII. This data indicates that for Oak Scour SO-50, Roller Cleaner, and Antifume GFD, there is a significant loss due to the volatility of the chemical at room temperatures. For the latter two chemicals, this is explained by the significant aromatic content as previously indicated in Table XLI.

## TABLE XLII

## SUMMARY OF BATCH ACTIVATED SLUDGE TREATABILITY DATA FOR CHEMICALS AND DYES

| CHEMICAL | AVERAGE MLSS (MG/L) | INITIAL COD (MG/L) | PERCENT COD REMOVED | | | COD REMOVED PER MLSS PER HOUR | | | OXYGEN CONSUMED PER MLSS PER HOUR | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 8 HRS | 12 HRS | 22 HRS | 8 HRS | 12 HRS | 22 HRS | 8 HRS | 12 HRS | 22 HRS |
| CARRIER NT | 1440 | 870 | 18 | 30 | 49 | 0.013 | 0.015 | 0.014 | 0.009 | 0.008 | 0.006 |
| AEROTEX 96 | 3825 | 55 | COD INCREASE DURING TEST | | | | | | 0.002 | 0.002 | 0.002 |
| SOLVECREST RB | 2705 | 370 | 50 | 56 | 72 | 0.008 | 0.006 | 0.004 | 0.010 | 0.010 | 0.008 |
| ROLLER CLEANER | 2470 | 305 | 5 | 11 | 30 | 0.001 | 0.001 | 0.002 | 0.009 | 0.009 | 0.008 |
| CAP LEV ME | 2555 | 455 | 22 | 35 | 54 | 0.005 | 0.005 | 0.0004 | 0.009 | 0.008 | 0.006 |
| OAK SCOUR SO-50 | 2325 | 200 | NO COD DECREASE DURING TEST | | | | | | 0.007 | 0.006 | 0.004 |
| AVITONE F | 1770 | 565 | 23 | 29 | 34 | 0.009 | 0.008 | 0.005 | 0.006 | 0.006 | 0.005 |
| ACETIC ACID | 2380 | 385 | - | - | 47 | - | - | 0.003 | - | - | 0.010 |
| EASTMAN BLACK T | 4365 | 625 | COD INCREASE DURING TEST | | | | | | 0.004 | 0.004 | 0.004 |
| LATYL BRILLIANT BLUE BGN | 3360 | 930 | 6 | 7 | 8 | 0.002 | 0.002 | 0.001 | 0.002 | 0.002 | 0.002 |
| INTRALAN BLACK BGL | 2530 | 650 | 8 | 8 | 10 | 0.003 | 0.002 | 0.001 | 0.002 | 0.001 | 0.001 |
| ALIZERINE GREEN CGN | 3520 | | COD INCREASE DURING TEST | | | | | | 0.002 | 0.002 | 0.002 |

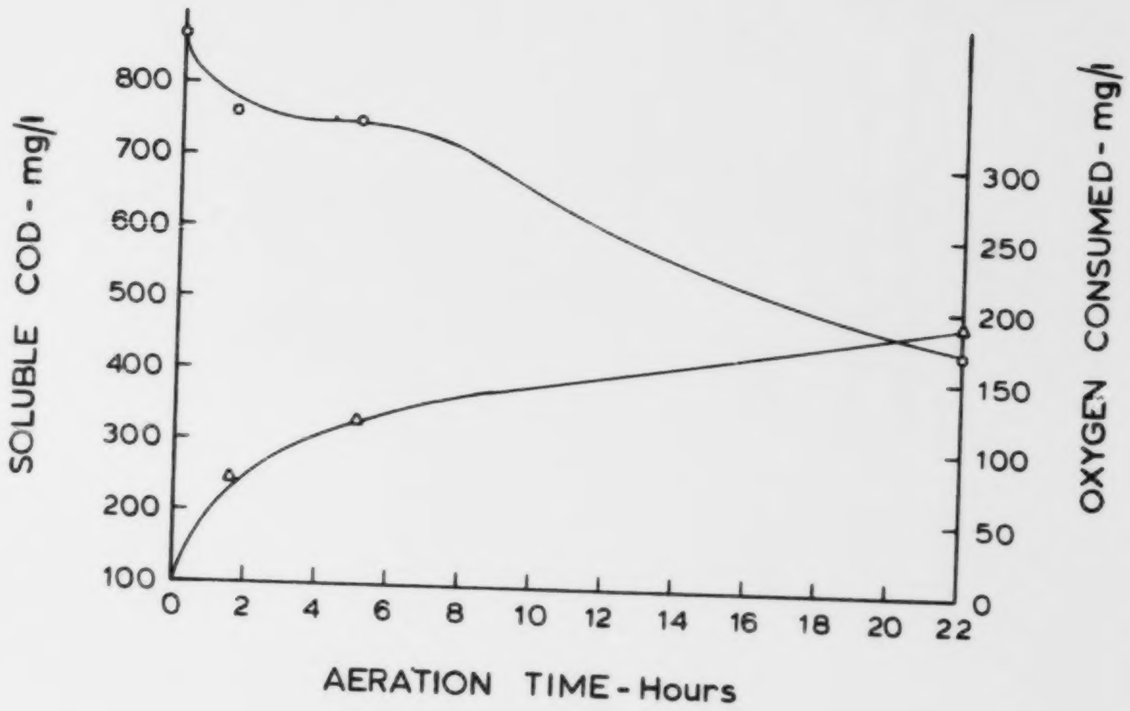


FIGURE L. Activated sludge treatability data for Carrier NT

# TABLE XLIII

## COD LOSS ON AERATION OF PRODUCTION CHEMICALS

| CHEMICAL | INITIAL CONCENTRATION (PERCENT) | TIME (HOURS) | TOTAL COD CONCENTRATION (MG/L) | LOSS (PERCENT) | SOLUBLE COD CONCENTRATION (MG/L) | SOLUBLE COD LOSS (PERCENT) |
|---|---|---|---|---|---|---|
| CARRIER NT | 0.10 | 0 | 962 | - | 867 | - |
| | | 2 | 992 | (3) | 867 | 0 |
| | | 23 | 869 | 10 | 807 | 7 |
| AEROTEX | 0.15 | 0 | 1050 | - | 290 | - |
| | | 2 | 1050 | 0 | 290 | 0 |
| | | 24 | 1070 | (2) | 310 | (7) |
| AVITONE F | 0.05 | 0 | 517 | - | 478 | - |
| | | 3 | 521 | (1) | 485 | (1) |
| | | 23 | 490 | 5 | 450 | 6 |
| OAK SCOUR SO-50 | 0.10 | 0 | 550 | - | 430 | - |
| | | 23 | 410 | 25 | 386 | 10 |
| ROLLER CLEANER | 0.10 | 0 | 1010 | - | 683 | |
| | | 3 | 760 | 25 | 644 | 6 |
| | | 23 | 425 | 60 | 431 | 37 |
| ANTIFUME GFD | 0.05 | 0 | 660 | - | 364 | - |
| | | 4 | 628 | 5 | 386 | (6) |
| | | 23 | 379 | 42 | 310 | 15 |

## PART C - ALUM COAGULATION TREATABILITY STUDIES

A series of tests were performed using production chemicals and dyes to determine the treatability characteristics in an alum coagulation process. The test method used was to measure COD and color removal with constant alum and polymer dose and supernatant pH. Tables XLIV through XLVI present a summary of the results of these tests.

The data indicates excellent color removal of the disperse dyes and significantly less removal of the acid dyes (Intralan Black BGL and Alizarine Fast Green CGN). The developed disperse dye also exhibited a lower level of removal. Among the disperse class, the COD removal percentage is much more widely scattered than the color removal percentages indicating that the dispersing agents that are part of the dyes mix may tend to remain in solution.

Figure XLV is a photograph illustrating the removal of disperse and acid dyes by alum coagulation using a synthetic dye bath and a multiple fiber test fabric.

# TABLE XLIV

## ALUM COAGULATION OF PRODUCTION CHEMICALS USING JAR TEST PROCEDURES

| CHEMICAL | INITIAL COD (MG/L) | FINAL COD (MG/L) | PERCENT COD REMOVAL |
|---|---|---|---|
| CARRIER NT | 1590 | 950 | 40 |
| AEROTEX WATER REPELLENT | 760 | 54 | 93 |
| SOLVECREST RB | 1,430 | 240 | 83 |
| CAP LEV ME | 930 | 300 | 68 |
| OAK SCOUR SO-50 | 2,010 | 430 | 79 |
| AVITONE F | 2,730 | 220 | 92 |
| ROLLER CLEANER | 1,620 | 670 | 59 |
| CAP LUBE LSP | 975 | 320 | 67 |
| HERRITON SWD | 1,390 | 810 | 42 |
| SANDOPAN DTC | 2,790 | 1,215 | 56 |
|  | 280 | 160 | 46 |
| CAP CARRIER BB | 1,700 | 585 | 66 |
| FORMIC ACID | 410 | 365 | 11 |
| RACOFIX NY | 6,930 | 415 | 93 |
| SOAP OFF 60 | 1410 | 590 | 58 |
| ANTIFUME GFD | 1,800 | 440 | 76 |
| OAKAPON X-70 | 1,800 | 440 | 76 |
| WINKLER FINISH NO. 1 | 940 | 570 | 39 |
| DISPERSING AGENT | 385 | 255 | 34 |

# TABLE XLV

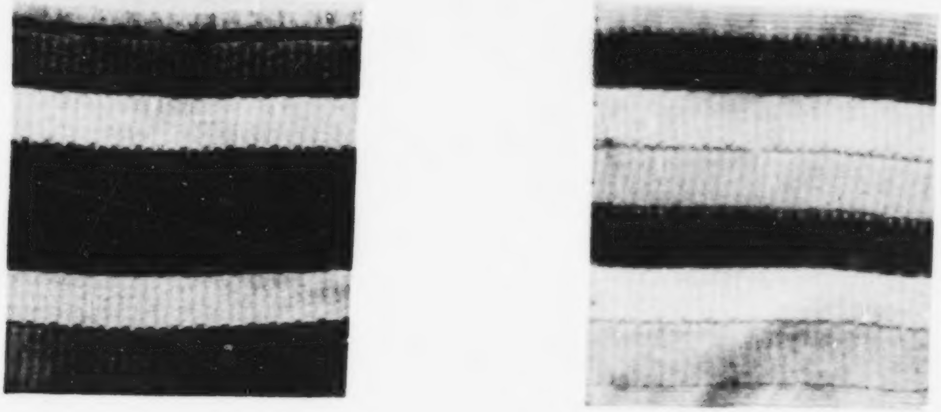
## ALUM COAGULATION OF PRODUCTION DYESTUFFS FOR COLOR REMOVAL USING JAR TEST PROCEDURES

| DYESTUFF | CLASS | INITIAL CONDITIONS |  | FINAL CONDITIONS |  | PERCENT |
|---|---|---|---|---|---|---|
|  |  | PH | COLOR | PH | COLOR | COLOR REMOVAL |
| **EASTMAN BLACK T** | DEVELOPED DISPERSE | 6.5 | 2240 | 6.9 | 740 | 67 |
| LATYL BRILLIANT BLUE BGN | DISPERSE | 8.5 | 1220 | 7.4 | 50 | 96 |
| AMACEL BLUE GP | DISPERSE | 6.7 | 1050 | 6.5 | 60 | 94 |
| AMACRON BRILLIANT BLUE G | DISPERSE | 6.4 | 345 | 6.5 | 5 | 98 |
| TERASIL NAVY BLUE 5GL | DISPERSE | 6.0 | 765 | 6.8 | 45 | 94 |
| INTRALAN BLACK BGL | ACID |  | 810 | 6.4 | 250 | 69 |
| RESOLIN BRILLIANT YELLOW 76L | DISPERSE | 6.2 | 158 | 6.5 | 15 | 90 |
| CALCOSPERSE RED 5G | DISPERSE | 6.1 | 585 | 6.7 | 20 | 96 |
| ALIZARINE FAST GREEN CGN | ACID | 6.2 | 1500 | 7.4 | 600 | 60 |
| CALCOSPERSE BLUE BGLK | DISPERSE | 6.5 | 810 | 6.8 | 35 | 96 |

## TABLE XLVI

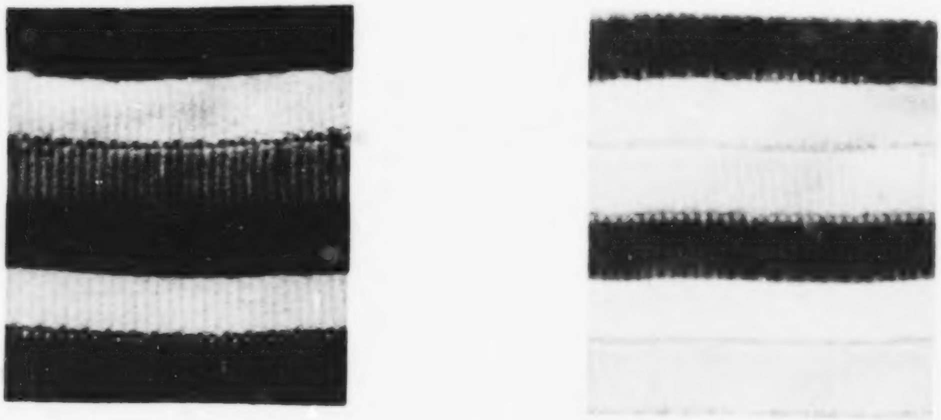
## ALUM COAGULATION OF PRODUCTION DYES
## FOR COD REMOVAL [illegible] JAR TEST PROCEDURES

| DYESTUFF | INITIAL COD (MG/L) | FINAL COD (MG/L) | PERCENT COD REMOVAL |
|---|---|---|---|
| EASTMAN BLACK T | 68 | 4 | 94 |
| LATYL BRILLIANT BLUE BGN | 148 | 22 | 85 |
| AMACEL BLUE GP | 335 | 26 | 92 |
| AMACRON BRILLIANT BLUE G | 142 | 61 | 57 |
| TERASIL NAVY BLUE SGL | 148 | 54 | 64 |
| INTRALAN BLACK BGL | 46 | 31 | 33 |
| RESOLIN BRILLIANT YELLOW 76L | 141 | 40 | 72 |
| CALCOSPERSE RED SG | 92 | 19 | 79 |
| ALIZARINE FAST GREEN CGN | 140 | 55 | 61 |
| CALCOSPERSE BLUE BGLR | 103 | 19 | 82 |



A. Disperse Blue 60
(10 gr/liter)

B. Acid Yellow 49
(10 gr/liter)



C. Combined Disperse Blue 60 and Acid Yellow 49

D. Dyebath mixture after alum coagulation

FIGURE LI. Dye removal by coagulation.

## PART D - CHARACTERIZATION OF PROCESS STREAMS

A number of process streams were sampled in the manufacturing area to provide an environmental characterization.

Table XLVII presents a summary of the results of repetitive sampling of the incoming municipal water used during manufacturing. This data indicates that the majority of the copper, mercury, and zinc contained in the untreated wastewater results from concentrations in the purchased plant water.

Tables XLVIII through L present typical wastewater characterization data for the major product lines at BRW obtained from several samples of actual production runs in the dyehouse. This information is only a very general approximation of the contribution of the various sources because of the wide variation possible in water volume, fabric weight, type and concentration of process chemicals.

Table LI presents a summary of the characteristics of finishing bath discharges and illustrates the low contribution of these chemicals to the wastewater pollutant level with the possible exemption of Aerotex due to a high volume of use (145,265 pounds; 65,890 kilograms per year).

A part of the finishing room operation is the air pollution control equipment or the tenter frame exhausts. An analysis of scrubber water from this equipment is presented in Table LII.

In addition to the discharge from isolated restrooms, the process water also contains blowdown water from the plant's water softeners and boilers. The results of analyses of these discharges is presented in Table LIII.

# TABLE XLVII

## CHARACTERIZATION OF MUNICIPAL WATER

| CONTAMINANT | AVERAGE VALUE (MG/L) | PERCENT OF EQUALIZED WASTEWATER VALUE |
|---|---|---|
| ALUMINUM [a] | 0.05 | 0.5 |
| CALCIUM | 0.26 | 12.9 |
| TOTAL CHROMIUM | N.D. | 0 |
| HEXAVALENT CHROMIUM | N.D. | 0 |
| COPPER [a] | 0.02 | 66.7 |
| IRON[a] | 0.05 | 12.0 |
| LEAD | N.D. | 0 |
| MAGNESIUM | 0.11 | 4.6 |
| NICKEL | N.D. | 0 |
| POTASSIUM | 0.66 | 15.7 |
| SODIUM | 8.97 | 5.8 |
| ZINC[a] | 0.15 | 100.0 |
| MERCURY | 0.0015 | 93.8 |
| CHLORIDE | 5.1 | 11.9 |
| SULFATE | 8.4 | 5.3 |
| TOTAL DISSOLVED SOLIDS | 100 | 19.6 |

[a] MEDIAN CONCENTRATION VALUE USED

# TABLE XLVIII

## CHARACTERIZATION OF WASTEWATER FROM APPAREL FABRIC MANUFACTURING

FABRIC: 100% NYLON APPAREL STYLE EQUIPMENT: ATMOSPHERIC BECK

LOT SIZE: 1100 POUNDS (499 KILOGRAMS)

PROCESS: LOAD → SCOUR → RINSE → RINSE → DYE → RINSE → RINSE → FIX → RINSE → RINSE → UNLOAD

CHEMICAL USE:

SCOUR BATH

FANAPON X-70
SODA ASH
HYDRO
CALGON

DYE BATH

ALKANOL ND
MERPOL OJS
MSP
CAP LUBE LSP
ACETIC ACID
CALGON
SULFER YELLOW PR
PURPLE MED. YELLOW SG

FIXING BATH

RACOFIX NY
ACETIC ACID

WASTEWATER CHARACTERISTICS:

| SAMPLE | WATER VOLUME (GALLONS) | (CUBIC METERS) | PH | COLOR (APHA) | BOD (MG/L) | COD (MG/L) |
|---|---|---|---|---|---|---|
| SCOUR BATH | 1,300 | 4.9 | 9.8 | 1,000 | 455 | 3,680 |
| DYE BATH | 1,300 | 4.9 | 5.0 | 2,800 | 356 | 4,500 |
| FIRST POST DYE RINSE | UNKNOWN | | 5.9 | 200 | 38 | 389 |
| FIXING BATH | 1,300 | 4.9 | 3.4 | 200 | 284 | 1,135 |

## TABLE XLIX

## CHARACTERIZATION OF WASTEWATER FROM VELOUR FABRIC MANUFACTURING

FABRIC: 100% ARNEL
VELOUR STYLE
EQUIPMENT: PRESSURE BEAM

LOT SIZE: 2700 POUNDS (1226 KILOGRAMS)

PROCESS: LOAD → RINSE → DYE → SCOUR → RINSE → SCOUR → RINSE → UNLOAD

CHEMICAL USE:

DYE BATH

CARRIER NT
NEUTROL 9
GLUCONIC ACID
HERRITON SWD
ANTIFUME GFD
CALGON
RESOLYN YELLOW 7GL
AMACEL BLUE GP
INTROLAN BLUE GREEN C DISPERSE II

AFTER DYE SCOUR

OAK SCOUR SO-50

WASTEWATER CHARACTERISTICS:

| SAMPLE | WATER VOLUME (GALLONS) | (CUBIC METERS) | PH | COLOR (APHA) | BOD (MG/L) | COD (MG/L) |
|---|---|---|---|---|---|---|
| INITIAL RINSE | UNKNOWN | | 5.2 | 5,000 | 4,500 | 2,940 |
| DYE BATH BEFORE PRESSURE | 3,000 | 11.4 | 5.3 | 14,000 | 21,400 | 7,300 |
| DYE BATH BEFORE DUMP | 3,000 | 11.4 | 4.9 | 12,000 | 19,100 | 6,300 |
| FIRST POST DYE SCOUR | UNKNOWN | | 5.2 | 5,000 | 4,200 | 700 |
| FINAL POST DYE RINSE | UNKNOWN | | 6.2 | 2,000 | 6,500 | 15 |

## TABLE L

## CHARACTERIZATION OF WASTEWATER FROM UNIFORM FABRIC MANUFACTURING

FABRIC: 80% POLYESTER/20% NYLON UNIFORM STYLE EQUIPMENT: CHAMBER

LOT SIZE: 1278 POUNDS

PROCESS: LOAD → PAD DYE → CHAMBER SET → ROTAMAT RINSE → PAD FINISH → DRY → UNLOAD

CHEMICAL USAGE:

DYE BATH

| | |
|---|---|
| MERPACYL ORANGE R | ACID DYE |
| ALIZERINE ASTROL B | ACID DYE |
| PALANIL BRILLIANT YELLOW 3G | DISPERSE DYE |
| LATYL CERISE NSN | DISPERSE DYE |
| LATYL BRILLIANT BLUE BGN | DISPERSE DYE |
| SUPERCLEAR 100N | THICKENER |
| ACETIC ACID | - |
| MONO-SODIUM PHOSPHATE | - |

FINISH BATH

| | |
|---|---|
| RESIN CP | POLYVINYL ACETATE |
| RAYSTAT B | ANTI-STAT |

CLEAN-UP

| | |
|---|---|
| ROLLER CLEANER | AROMATIC CHEMICAL |

WATER CHARACTERISTICS:

| SAMPLE POINT | WATER VOLUME (GALLONS) | WATER VOLUME (CUBIC METERS) | PH | COLOR (APHA) | BOD (MG/L) | COD (MG/L) |
|---|---|---|---|---|---|---|
| DYE BATH | 60 | 0.25 | 4.9 | 24,000 | 160 | 225 |
| RINSE | 500 | 1.89 | 6.6 | 5 | 2 | 29 |
| FINISH BATH | 80 | 0.30 | 5.4 | 15 | 0 | 1540 |
| INITIAL EQUIPMENT WASH | 50 | 0.19 | 8.5 | 2,300 | 810 | 3970 |
| FINAL EQUIPMENT WASH | 250 | 0.95 | 6.6 | 500 | 18 | 57 |

## TABLE LI

## CHARACTERISTICS OF FINISH BATH DISCHARGES

| FINISH | FABRIC USED WITH | CONCENTRATION IN BATH (PERCENT) | USE RATE | BOD (MG/L) | COD (MG/L) | PH |
|---|---|---|---|---|---|---|
| WINKLER NO. 1 | APPAREL-NYLON | 1.0 | 1 BATCH/2-3 LOTS | 71 | 2,750 | 5.0 |
| VIVA | ARNEL | 0.5 | 1 BATCH/2-3 LOTS | 2 | 42 | 4.4 |
| AEROTEX | ARNEL | 2.0 | 1 BATCH/HOUR | 56 | 127 | 3.9 |
| SOLVOSOFT 115 | POLYESTER | 2.5 | 1 BATCH/LOT | 4 | 217 | 8.6 |
| RESIN CP | NYLON-POLYESTER | 1.5 | 1 BATCH/LOT | 0 | 165 | 5.4 |

NOTE: BATH VOLUME = 215 GALLONS (0.81 CUBIC METERS)

# TABLE LII

## SCRUBBER WATER FROM TENTER FRAME AIR POLLUTION CONTROL EQUIPMENT

| | |
|---|---|
| BOD: | 6,400 MG/L |
| COD: | 10,400 MG/L |
| SUSPENDED SOLIDS: | 100 MG/L |
| VOLATILE SUSPENDED SOLIDS: | 100 MG/L |
| TOTAL SOLIDS: | 5,560 MG/L |
| TOTAL VOLATILE SOLIDS: | 2,060 MG/L |
| PH BEFORE NEUTRALIZATION: | 4.2 |
| WEEKLY WATER VOLUME: | 5,000 GALLONS (18.9 CUBIC METERS) |

# TABLE LIII

## CHARACTERISTICS OF BLOWDOWN WATER

| SOURCE | PH | SS (MG/L) | DISSOLVED SOLIDS (MG/L) | ORTHOPHOSPHATE (MG/L) |
|---|---|---|---|---|
| WATER SOFTENER | 6.3 | 52 | 15 | - |
| BACK WASH BRINE | 6.1 | - | 25 | - |
| RINSE | 6.2 | - | 60 | - |
| BOILER BLOWDOWN | 11.2 | - | 2050 | 68 |

## PART E - MANUFACTURING EFFECTS ON WASTEWATER CHARACTERISTICS

Data on major production and wastewater parameters collected during the study period was examined to determine the significant correlations between the two sets of information. Table LIV presents a list of the approximate unit water rates for the major product lines at the plant. The overall unit water rate was determined to be 12 gallons/pound (0.1 cubic meters/kilogram) of product and the typical daily range was found to range between 10 and 15 gallons/pound (0.8 and 1.2 cubic meters/kilograms) of product. This data was developed by estimating the rate from formula cards and refining the estimate by comparison of calculated and actual total flow values.

Of the correlations attempted between equalized raw waste characteristics and production volume by product style, only velour style (beam) production demonstrated any significant correlation. This result could be expected considering that velour production by pressure beam dyeing accounts for 54 percent of the total yearly mill volume. Figures LII through LIV illustrate the effect of beam production volume on wastewater flow, influent COD concentration and influent color concentration respectively. Accordingly to Figure LII, the water use rate for beam production was 9 gallons per pound (75.1 liters per·kg) or slightly higher than the 8 gallons per pound (66.8 liters per kg) determined by the data presented in Table LIV.

Using Figure V of Section IV of which correlates total and beam production, and the data presented in this Section, it is possible to predict the major influent waste characteristics for a given mill production level.

It was anticipated that a correlation would be possible between effluent color concentration and automotive production, since the acid dyes used in manufacturing this fabric were found to be the major dyestuffs remaining after alum coagulation. However, because of the number of variables encountered in the treatment system no correlation was possible.

# TABLE LIV

## UNIT WATER RATES FOR PRODUCTION PROCESSES

| EQUIPMENT | FABRIC | UNIT WATER RATE<br>(GALLONS/POUND) | <br>(LITERS/KILOGRAMS) |
|---|---|---|---|
| BEAM | ARNEL/NYLON | 8 | 66 |
| CHAMBER | NYLON/POLYESTER AND OTHER | 2.5 | 21 |
| ATMOSPHERIC BECK | AUTOMOTIVE NYLON | 28 | 232 |
|  | ALL OTHER | 15 | 124 |
| PLANT AVERAGE | - | 12 | 100 |

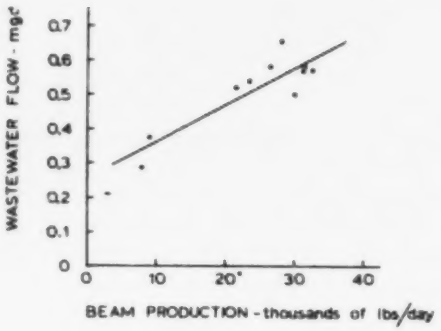


**FIGURE LII.** Correlation of wastewater flow with beam production

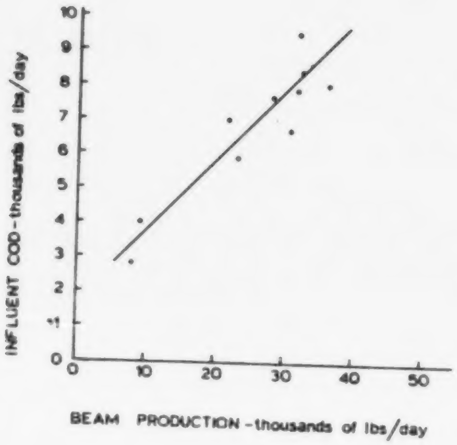


**FIGURE LIII.** Correlation of wastewater COD with beam production

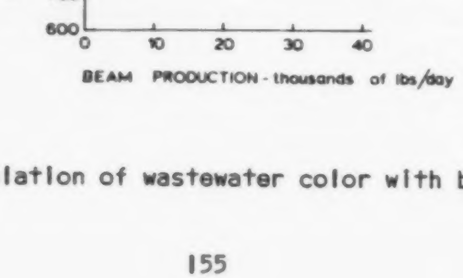


**FIGURE LIV.** Correlation of wastewater color with beam production

# SECTION XV

## SUMMARY OF RESEARCH ACTIVITIES ON ALTERNATIVE TREATMENT PROCESSES

### PART A - INITIAL TREATABILITY STUDIES

The design of the full-scale BRW treatment plant was based on the data gathered during a three-month bench-scale treatability study using continuous feed reactors to define the activated sludge process. This investigation, conducted in early 1970, determined that the process would perform as indicated in Table LV when operated at a 10.8 hour aeration time and a 2820 mg/l mixed liquor suspended solids concentration.

TABLE LV

PILOT SCALE ACTIVATED SLUDGE PERFORMANCE

| CONTAMINANT | INFLUENT VALUE (MG/L) | PERCENT REMOVAL | EFFLUENT VALUE (MG/L) |
|---|---|---|---|
| BOD | 350 | 90.6 | 33 |
| COD | 1060 | 60.0 | 435 |
| SUSPENDED SOLIDS | 47 | (55.3) | 73 |

Insufficient data was available from this initial study to develop a mathematical model. The summary data presented above does indicate that a much higher percentage of biological oxidation was obtained by the pilot and full-scale performance is only partially explained by the insoluble BOD and COD contributed by the full-scale effluent suspended solids.

The estimated soluble BOD and COD removal percentages were 88 and 45 respectively for the full-scale system as described in Section VIII of this report. In comparing these values to those in Table LV, there is a significant difference in the soluble COD removal percentage. This difference is attributed to a change in production chemical use between the early 1970 and the 1972 - 1973 periods.

During the pilot scale studies, effluent from the activated sludge system was alum coagulated on a daily batch basis. Table LVI presents the summary of data gathered during this study when the alum dose was 200 mg/l. These removal percentages are in general agreement with those obtained by the full-scale equipment.

## TABLE LVI

## PILOT SCALE ALUM COAGULATION PERFORMANCE

| CONTAMINANT | INFLUENT VALUE (MG/L) | EFFLUENT VALUE (MG/L) | PERCENT REMOVAL |
|---|---|---|---|
| BOD | 33 | 7 | 78.8 |
| COD | 435 | 174 | 60.0 |

## PART B - BATCH ACTIVATED SLUDGE TREATABILITY STUDIES FOR THE TOTAL PROCESS STREAM

During the course of the grant project, a number of batch activated sludge treatability evaluations were made. A wide variation in data was obtained by these evaluations when equalized raw waste was used as the substrate. Figure LV presents the data from one such test, and while there was a significant variation in removal rates in these evaluations, the general shape of the substrate COD, oxygen consumption and mixed liquor solids curves were very similar. The most unusual part of these graphs is the apparent increase in soluble COD after between 5 and 10 hours of aeration and after a significant decrease in COD had occurred. This observation was repeated in each test and was felt to indicate either a change in the microorganism population or a partial conversion of insoluble COD material to soluble COD material.

The VMLSS curve was also repeated during the ten evaluations that were made. Several evaluations were made with a very low initial mixed liquor solids concentration in order to detect solids growth. However there was no detectable growth even at these low levels.

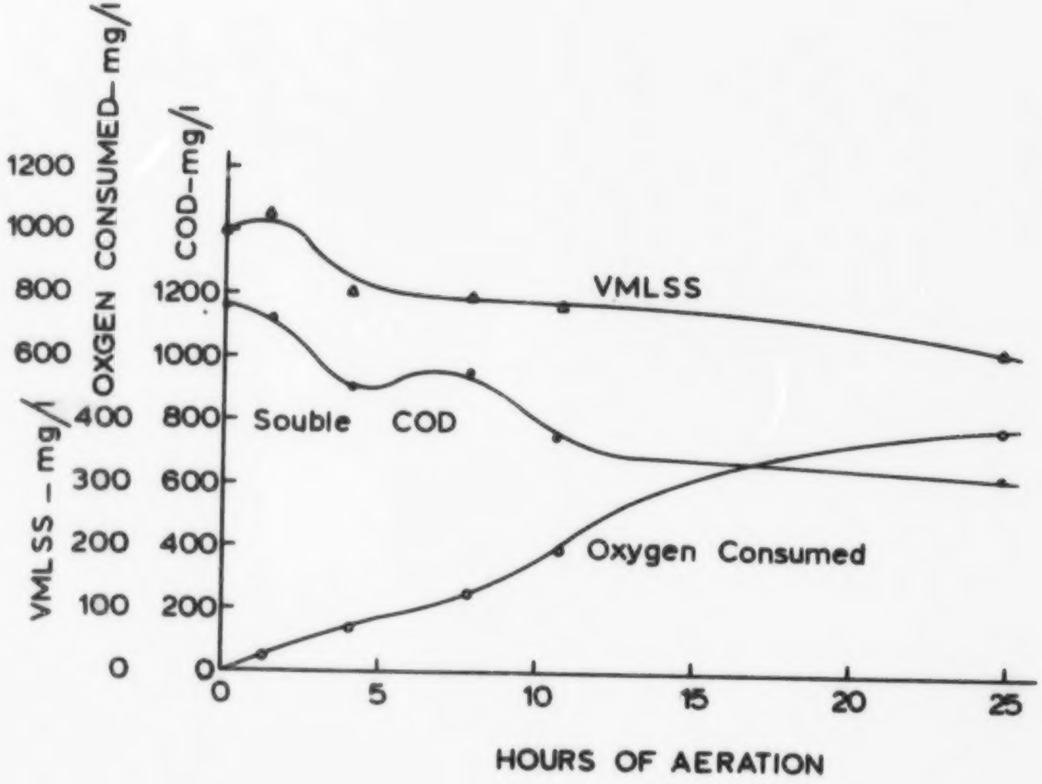


FIGURE LV. Batch activated sludge treatability data

## PART C - ALTERNATIVE COAGULANTS

At various times since the start of research activities on the present BRW treatment system, investigations have been conducted to determine the most effecitve and economical primary coagulant. Figure LVI indicates the results of a typical analysis in which equalized raw waste was coagulated with alum, ferric chloride, and lime. These data indicate that lime at a dosage of up to 600 mg/l provides very little COD removal and that alum and ferric chloride provides substantial COD removal. Alum was found to give slightly better performance (removal of COD, color, and suspended solids) than the ferric chloride and was judged to be the easier raw material to handle. Ferric chloride was found to yield better performance than alum, however, if the pH of the wastewater was lowered to the 2.5 to 3.0 range during the rapid mixing. A cost comparison between this proposed system and the alum system indicated that the costs associated with acid addition and increased caustic soda addition required for neutralization would far exceed the anticipated benefits for this process alternate.

In the last several years there has been a significant advance in the application of polymer chemistry to wastewater treatment, and as a result there is an increasing number of cationic polymers introduced that have the potential for replacing the anionic metal salts that have historically been used for coagulation of colloidal material in water and wastewater. A number of these polymers were investigated, and the results produced by two deserve comment.

First, a highly charged, and high molecular weight liquid cationic polymer of a melamine construction manufactured by American Cyanamid Co. (Cyanamid 509C) was found to provide excellent treatment of the activated sludge effluent. At a dosage of 2500 mg/l (approximately 250 mg/l on a dry basis) the polymer consistently produced a jar test supernatant of less than 100 APHA color units and on several occassions produced a colorless supernatant. Use of the polymer at this dosage was not economically feasible, but the results justified additional polymer evaluations. Another liquid cationic (Cyanamid 573C) of a polyamine construction and with similar physical properties, was found to produce good results at a dosage of 100 mg/l when alum was also added at a dosage of 50 mg/l with

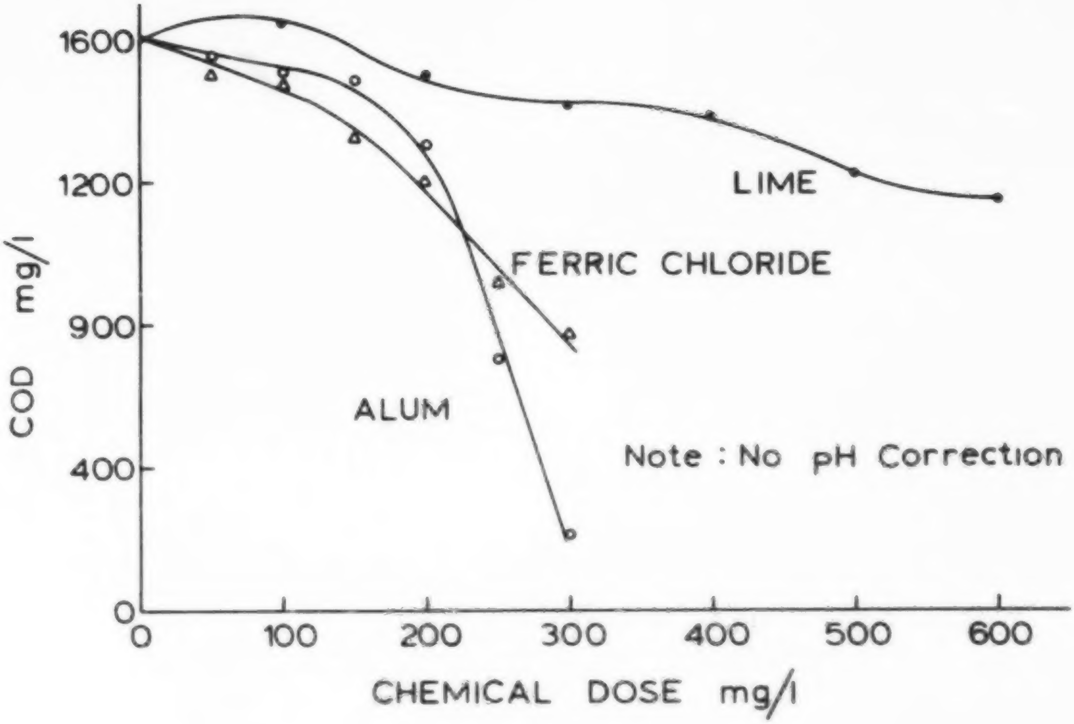


FIGURE LVI. Coagulation of equalized raw waste an anionic polymer (Cyanamid 837A) at a dose level of 3.0 mg/l. This polymer produced a slightly better jar test supernatant than the alum alone and as an additional benefit depressed the pH to only 6.4, compared to 4.0 for the alum alone. This latter point is significant in that bulk supplies of liquid caustic soda for neutralization were in scarce supply at the time this report was being written.

## PART D - POLYMER ADDITION TO THE ACTIVATED SLUDGE SYSTEM

During the settling phase of the activated sludge process, aggregation of the biological floc is brought about by naturally occurring enzymes and polymers. However, there is a wide variation in the effectiveness of the flocculation step that affects the effluent suspended solids level and the waste sludge concentration.

Two full-scale trials were made to investigate the possible benefits of the addition of a polymer chemical to the activated sludge influent to aid the flocculation process. A Nalco Chemical Co. cationic polymer (73C32) was chosen for this experiment based on previously favorable thickening experiments.

During the first trial, the polymer was added at an average dosage of 12 mg/l but a bulking situation rapidly developed. This situation was determined to be a result of an unusually high mixed liquor solids concentration without a compensatingly higher recycle rate.

During the second trial, the polymer was added at an average dosage of 15 mg/l. There was no detectable decrease in effluent suspended solids or decrease in the sludge volume index, but there did seem to be an increase in effluent turbidity during the trial. As a result, it was judged that cationic polymer addition did not exhibit any positive influence on the activated sludge clarification process.

## PART E - TWO STEP ALUM COAGULATION

During the course of the study, observation of the alum coagulation process indicated improved color and COD removal during periods when a failure in the caustic soda feed system resulted in a low pH in the clarifier. This observation prompted an investigation of the pH effect on contaminant removal and typical results from this investigation have previously been illustrated in Figures XXIX through XXXII of Section IX of this report.

For color, Figure XXX indicates maximum removal at a pH of 4.5 - 5.0 and this result has been consistently confirmed. A partial cause of the apparent lower color value at a lower pH was due to the dependency on pH of the color measurement method. However, experimental data indicates that the primary cause of the increased color removal was due to decreased solubility of the dye precipitates or the coagulant/dye complexes at the lower pH as illustrated by the data in Table LVII.

### TABLE LVII

### COLOR REMOVAL BY TWO STEP ALUM COAGULATION

| PRIMARY PH | PRIMARY COLOR | SECONDARY COLOR AT 6.5 PH | SECONDARY COLOR AT 7.5 PH |
|---|---|---|---|
| 3.9 | 120 | 100 | 120 |
| 4.7 | 90 | 90 | 90 |
| 5.9 | 95 | 100 | 120 |
| 6.5 | 140 | 140 | 150 |
| 7.4 | 200 | - | 200 |

The data in Table LVII indicates the following:

- The point of minimum color during primary coagulation occurs at a pH of 4.7
- The color level during the primary coagulation was found to vary significantly primarily as a result of changing solubility with pH

The point of maximum insolubility for aluminum and chromium was found to be at a pH above 6.0, and as a result there was additional precipitation of solids when the primary supernatant from a two step process was neutralized as illustrated by the data in Table LVIII.

## TABLE LVIII

## SOLIDS GENERATION IN TWO STEP ALUM COAGULATION

| PRIMARY PH | SUSPENDED SOLIDS (MG/L) SECONDARY PH VALUE PH = 6.5 | PH = 7.5 |
|---|---|---|
| 3.9 | 138 | 116 |
| 4.8 | 22 | 52 |
| 5.7 | 4 | 4 |
| 6.5 | 2 | 2 |
| 7.6 | - | 6 |

Solids generated during the second stage neutralization could be removed by either clarification on filtration. The experience of BRW in operating the present alum coagulation clarifier indicated that filtration was the only way to insure a continual low solids effluent. The expected solids load to the filtration step (50 - 75 mg/l) would permit the design of a filtration system with acceptable backwash requirements. The literature suggests the use of a dual media filter (anthracite and sand) in handling the expected metal hydroxide solids at a 10 gallon/minute/squre foot (0.41 cubic meters/min/square meter) filtration rate to produce an effluent with essentially no suspended solids.

The two-step alum coagulation experiments conducted during the study indicated that an improved process consisting of (1) primary coagulation and clarification at a 4.5 - 5.0 pH (2) neutralization of the clarifier overflow to a pH of 6.5 - 7.0 and (3) filtration of the neutralized waste would yield an effluent with the characteristics presented in Table LVIX.

## TABLE LVIX

## ESTIMATED EFFLUENT CHARACTERISTICS FROM A TWO-STEP ALUM COAGULATION PROCESS

| CONTAMINANT | CONCENTRATION | EFFLUENT WEIGHT RATIO |
|---|---|---|
| BOD | <25 (MG/L) | 2.2 LB/LB PRODUCT |
| COD | 300 (MG/L) | 26.9 LB/LB PRODUCT |
| SUSPENDED SOLIDS | 15 (MG/L) | 1.3 LB/LB PRODUCT |
| COLOR | 200 (APHA) | - |

## PART F - CHEMICAL OXIDATION

The original treatment system at BRW included a chlorination step, but the unit was designed primarily for disinfection rather than for additional color removal. As a result, chlorine dosage was limited to a maximum of 10-15 mg/l, contact time was limited to 20 minutes, and no appreciable color removal was achieved. The results of a brief laboratory study to remove color from a low initial color stream is presented in Figure LVIII and indicate a chlorine dosage of 20-30 mg/l was required to produce an effluent color of 50 APHA units.

Similar experiments were conducted using hydrogen peroxide as the oxidizing chemical, but color removal was not achieved unless the wastewater pH was reduced below a 4.0 value. At this pH level, color removals to 50 APHA units were obtained without the color returning after neutralization.

Since the residual color left after alum coagulation was determined to be due to a low concentration of soluble dyes, it was felt that a chemical oxidation process would provide the most economical method of color removal. When readily available oxidants such as chlorine and hydrogen peroxide did not achieve the desired results, several bench scale tests were made using ozone. The oxidation potential of ozone is approximately twice that of chlorine and is the highest of any practical oxidizing chemical. These tests proved successful, and it was decided to proceed with a pilot plant evaluation. A mobile facility with the capability of processing a 15 gallon (0.06 cubic meter) per minute side stream of alum coagulation effluent was installed at the BRW plant and operated for a period of two months.

This mobile unit consisted of two, 15 foot (4.6 meter) high, 0.75 foot (0.23 meter) diameter plexiglass columns with intermediate holding tanks to allow multiple contacting of the effluent.

Ozone was generated on-site in an ozone in oxygen stream. The unit was run in a continuous mode at various flow rates and ozone dosages with samples being taken after the contact unit reached equilibrium.

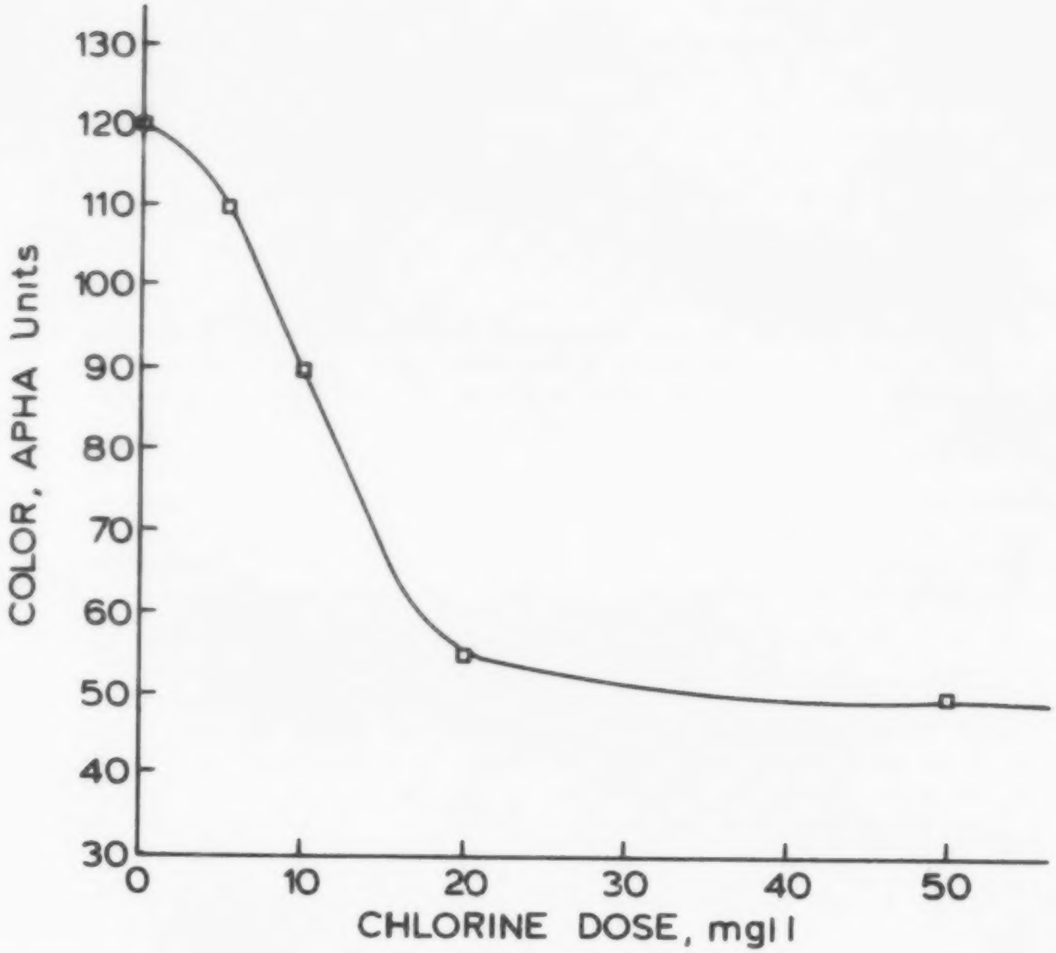


FIGURE LVII. Residual color removal by chlorination

The major conclusions resulting from this work are listed below and are illustrated in Figures LVIII through LX.

- Color removal was found to proceed very rapidly, with the majority of the removal occurring in the first contact step
- Color removal was found to be dependent on the feedwater pH value, with an acidic waste (pH less than 5.0) reaching a lower color level much more rapidily than a neutral waste
- For a waste at a pH less than 5.0, approximately 75 percent of the color was removed in the initial contact step at a contact time of 3.5 minutes, and if the initial contact time were increased to 10.0 minutes approximately 90 percent of the color would be removed.
- The system was operated with an excess of applied ozone in most experiments, but experiments at reduced dosage levels indicated a critical initial color to ozone ratio of 40 to 50 APHA units per mg/l of ozone in water for the initial contact step. At a ratio higher than this range, color removal was substantially reduced.
- For the initial contacting step, the color removal rate occurred in two distinct patterns. First, the majority of the color removal obtained appeared to be mass transfer rather than time dependent. Second, additional color removal appeared to be contact time dependent.
- Color removal in the secondary contacting steps was found to range between 40 and 60 percent at all pH values and was found to occur almost instantaneously. The critical ozone in water concentration was determined to be between 3 and 5 mg/l for the secondary steps.
- A feedwater COD value of 300 mg/l was found to be critical to the successful performance of the process, and feedwater COD values in excess of this value resulted in greatly reduced color removal in all contacting steps
- COD removal was found to be dependent on both contact time and ozone dosage level. For a total ozone dosage of 15.0 mg/l through two stages and a total contact time of 10.0 minutes, the COD removal would be approximately 8.5 percent.

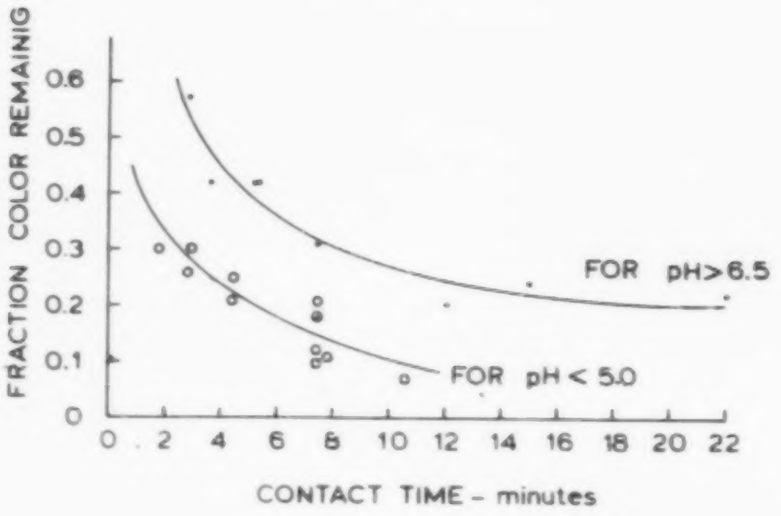


FIGURE LVIII. Initial color removal by ozonation

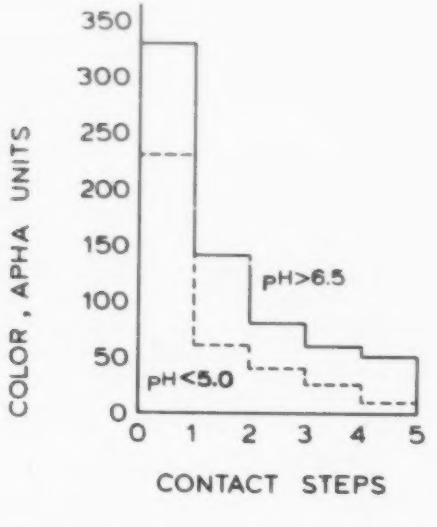


FIGURE LIX. Typical color removal by ozonation

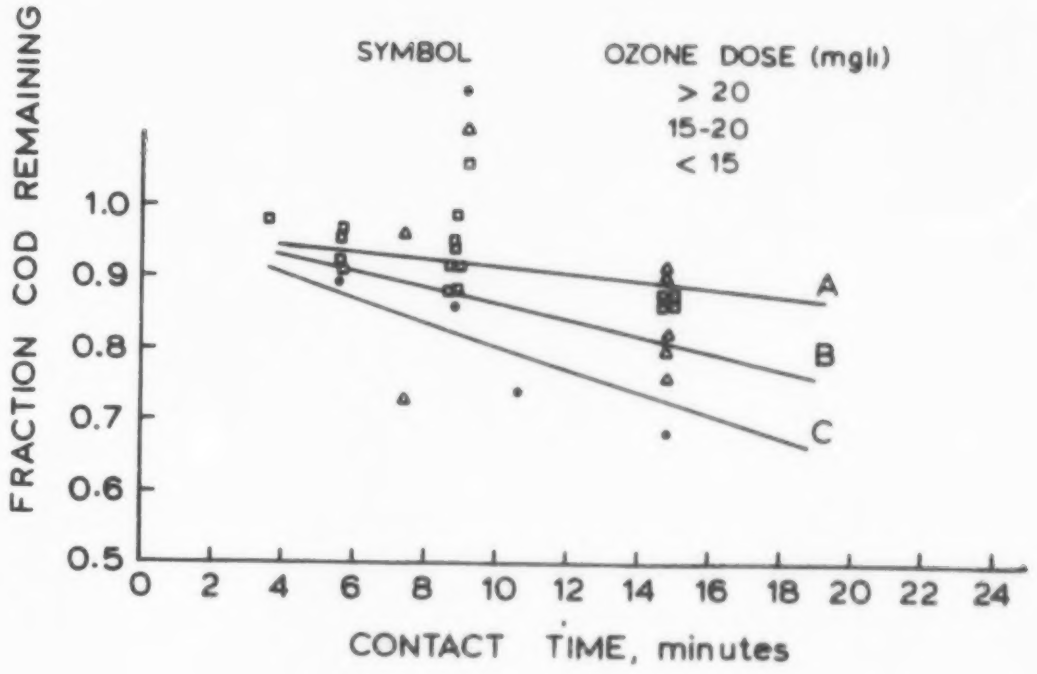


FIGURE LX. COD removal by ozonation

- An increase in BOD across the process was estimated to be due to the conversion of refractory dyes to degradable products by the oxidation of the color producing bonds of the dye molecules. BOD generation was found to range between 0.01 and 0.03 mg/l per APHA unit of color removed when the total ozone dosage in two contact stages was less than 25 mg/l and the total contact time was less than 20 minutes. This generation rate increased to 0.04 to 0.06 mg/l per APHA unit when the total ozone dose or detention time exceed 25 mg/l or 20 minutes.

- The turbidity of the alum coagulation effluent was reduced from a range of 25 - 75 JTU to a range of 5 - 10 JTU by the process

- The median reactor ozone utilization efficiency was determined to be 55 percent.

Based on the results of this pilot plant work, a process design was developed for the ozone process combined with two-step alum coagulation and filtration processes to provide a complete color removal system. In this process scheme, the coagulation and settling portion of the first step of the alum process would be conducted with the feedwater pH controlled to a 4.5 - 5.0 range. Clarifier overflow would be pumped through an ozonation process using three contact vessels in series. Two parrallel trains of contactors would be used to maintain a resonable range of contact time with variable flow. The ozone would be generated at a one percent concentration from air. Flow in the contactors would be alternately co-current/counter-current to the gas flow. High shear mixing would be provided to increase design gas transfer efficiency in the first two contactors but porous diffusers could be used in the third contactor to minimize feedwater pumping requirements. Ozonated effluent would then be neutralized and sent to a train of anthracite and sand filters. Design parameters for this process series is presented in Table LX.

The process would be fully instrumented to control ozone generation (based on effluent color) wastewater pH, and filtration pressure loss.

For the total system, it was estimated that there would be no net BOD increase since the soluble BOD generated by the ozone system would be compensated for by the insoluble BOD removed by filtration.

Cost data for the process is presented in Table LXI.

## TABLE LX

## SUMMARY OF OZONE AND FILTRATION PROCESS DESIGN PARAMETERS

| | | |
|---|---|---|
| FIRST STEP<br>COAGULATION EFFLUENT | | |
| PH | 4.5 - 5.0 | |
| COD | 300 MG/L | |
| BOD | 25 MG/L | |
| COLOR | 200 APHA | |
| SUSPENDED SOLIDS | 50-75 MG/L | |
| DISSOLVED OXYGEN | 2.0 MG/L | |
| OZONE SYSTEM | | |
| FIRST STAGE | | |
| DETENTION TIME | 4.0 MINUTES | |
| OZONE DOSE | 7.5 MG/L | |
| SECOND STAGE | | |
| DETENTION TIME | 3.0 MINUTES | |
| OZONE DOSE | 3.0 MG/L | |
| THIRD STAGE | | |
| DETENTION TIME | 2.0 MINUTES | |
| OZONE DOSE | 2.0 MG/L | |
| OZONE TRANSFER EFFICIENCY | 75.0 PERCENT | |
| OZONE REQUIREMENT FOR 1.25 MGD | 175 POUNDS/DAY | |
| FILTRATION SYSTEM | | |
| FILTRATION RATE | 12 GAL/MIN/SQ.FT. | |
| FILTER RUN TIME | 8 HOURS | |
| BACKWASH RATE | 20 GAL/MIN/SQ.FT. | |
| BACKWASH RUN TIME | 5 MINUTES | |
| AIR SCOUR RATE | 10 SCFM/SQ.FT. | |
| FINAL EFFLUENT | | |
| PH | 6.5 MG/L | - |
| COD | 275 MG/L | 24.6 LB/LB PRODUCT |
| BOD | <25 MG/L | < 2.2 LB/LB PRODUCT |
| COLOR | 50 APHA | - |
| SUSPENDED SOLIDS | 15 MG/L | 1.3 LB/LB PRODUCT |
| DISSOLVED OXYGEN | 5.0 MG/L | - |

# TABLE LXI

# SUMMARY OF OZONE AND FILTRATION COST DATA

| | |
|---|---|
| CAPITAL COST (1973 DOLLARS) | |
| TWO STEP ALUM COAGULATION | $25,000 |
| OZONATION | $250,000 |
| FILTRATION | $175,000 |
| TOTAL | $450,000 |
| OPERATING COST (1973 DOLLARS) | |
| TOTAL | $50,000 |
| PER DESIGN THOUSAND GALLONS TREATED PER YEAR | $0.14 |
| PER DESIGN CUBIC METERS TREATED PER YEAR | $0.03 |

## PART G - POWDERED ACTIVATED CARBON AIDED ACTIVATED SLUDGE

Powdered activated carbon addition to the aeration basin of an activated sludge process has been suggested as a method of increasing organic chemical removal including a reduction of dyes by adsorption of the chemicals on the carbon particle. By adsorbing the chemicals, the carbon apparently provides a site for additional biological action not obtainable by a simple dispersion of biofloc in a dilute solution. Once a critical mixed liquor carbon concentration is obtained, then daily addition of the carbon is required only make-up loss by sludge wasting and loss over the clarifier weir.

During the course of the study, two full-scale tests were made of the process modification were made using Darco XPH as manufactured by ICI America, Inc., and data from these tests are presented in Table XVII.

The first trial occurred just as the system was recovering from an upset condition and dispersed growth conditions probably resulted in heavy carbon loss from this system. The data for this period indicates removals below predicted levels and can be attributed to this condition. For the second trial, the system was operating well and there was probably a high build-up of carbon in the system, approaching the calculated level of 515 mg/l. For this period, the COD, color, and ammonia nitrogen removals were significantly better than predicted from the mathematical models presented in Section VIII which indicates that the carbon was having a beneficial effect on the process.

Data presented in Part H of this Section indicates that a carbon concentration of approximately 1500 mg/l is necessary in order to achieve a high color removal level. It is estimated, that a mixed liquor carbon concentration of this magnitude would be required in order to achieve an increase in COD and color removals that would significantly affect the total treatment system discharge levels.

## TABLE LXII

## PERFORMANCE OF A POWDERED ACTIVATED CARBON AIDED ACTIVATED SLUDGE SYSTEM

| PARAMETER | TRIAL I | TRIAL II |
|---|---|---|
| INFLUENT CONDITIONS | | |
| FLOW (MGD) | 0.573 | 0.712 |
| BOD (MG/L) | 444 | 463 |
| COD (MG/L) | 1910 | 1320 |
| COLOR (APHA) | 1620 | 1020 |
| DETERGENT (MG/L) | 26 | - |
| AMMONIA NITROGEN (MG/L) | - | 10.7 |
| AERATION BASIN | | |
| RETENTION TIME | 14.1 HOURS | 11.2 HOURS |
| MLSS | 3530 MG/L | 3160 MG/L |
| VMLSS | 2910 MG/L | 2530 MG/L (ESTIMATED) |
| CALCULATED CARBON IN AERATION BASIN | - | 515 MG/L |
| CARBON FEED RATE | 90 MG/L | 55 MG/L |
| ACTUAL REMOVALS | | |
| BOD (MG/L) | 72 PERCENT | 76 PERCENT |
| COD (MG/L) | 25 PERCENT | 46 PERCENT |
| COLOR (APHA) | 18 PERCENT | 39 PERCENT |
| DETERGENT (MG/L) | 76 PERCENT | - |
| AMMONIA NITROGEN (MG/L) | - | 76 PERCENT |
| PREDICTED REMOVALS | | |
| BOD (MG/L) | 82 PERCENT | 78 PERCENT |
| COD (MG/L) | 41 PERCENT | 30 PERCENT |
| COLOR (APHA) | 35 PERCENT | 23 PERCENT |
| DETERGENT (MG/L) | 80 PERCENT | - |
| AMMONIA NITROGEN (MG/L) | - | 65 PERCENT |

## PART H - GRANULAR CARBON ADSORPTION

The removal of dissolved organic chemicals including dyes by granular carbon adsorption has been widely reported in the literature in recent years. The process has been found to be an excellent method of treatment in a tertiary mode, but the regeneration costs of the carbon after exhaustion have generally been too high for acceptance in full-scale systems except on unusually high strength wastes.

Several investigations of the BRW effluent were made to determine what the probable removal rates were for residual COD and color from the present treatment system. It was felt that the removal rates could be sufficiently high to consider disposal rather than regeneration of the exhausted carbon. Typical isotherms derived from the addition of granular carbon (Darco 8X35) to various effluents are presented in Figures LXI and LXII and the data from these graphs are summarized in Tables LXIII and LXIV.

### TABLE LXIII

### REMOVAL OF COLOR BY ACTIVATED CARBON

| EFFLUENT | CARBON CAPACITY (% APHA UNITS REMOVED PER % CARBON IN SOLUTION | DESIGN INFLUENT COLOR (APHA) | DESIGN EFFLUENT COLOR (APHA) | CARBON USAGE (LBS/ GAL) | (KG/CU METER) |
|---|---|---|---|---|---|
| ACTIVATED SLUDGE | 5000 | 800 | 50 | 1.6 | 320 |
| ALUM COAGULATION | 4000 | 200 | 50 | 1.4 | 280 |

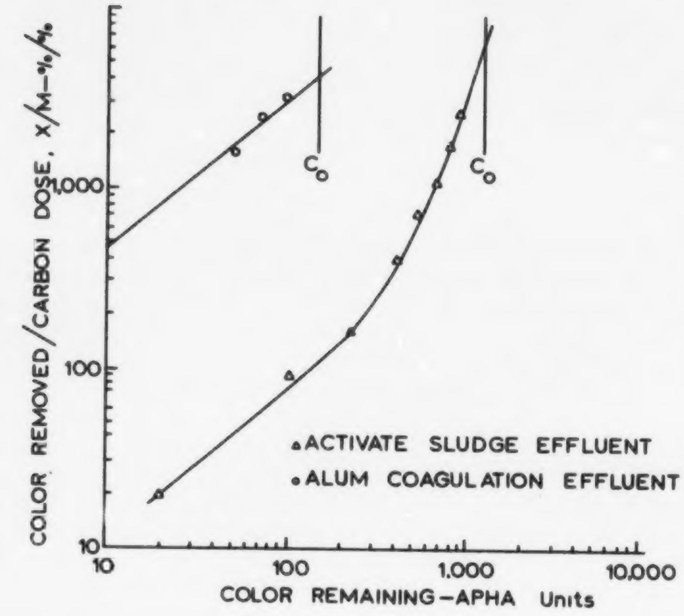


FIGURE LXI. Activated carbon isotherms for color

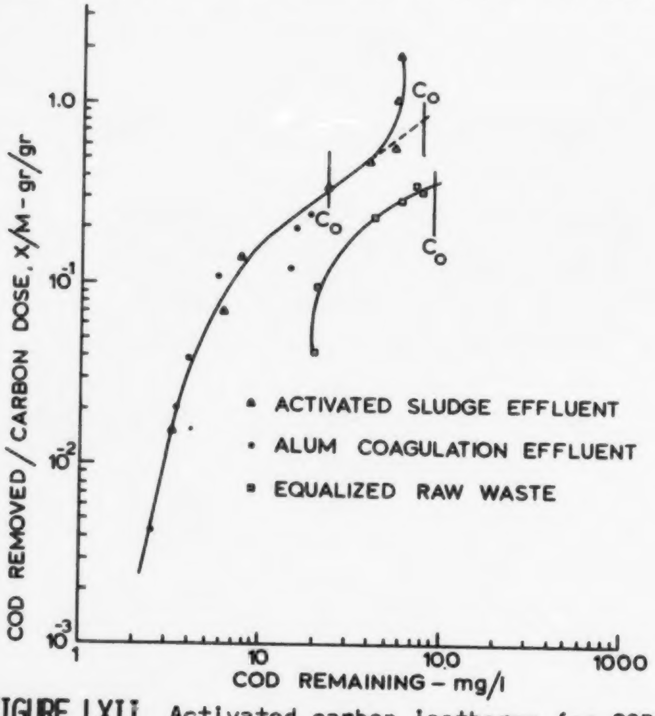


FIGURE LXII. Activated carbon isotherms for COD

## TABLE LXIV

## REMOVAL OF COD BY ACTIVATED CARBON

| EFFLUENT | CARBON CAPACITY (WT. OF COD REMOVED PER WT. OF CARBON IS SOLUTION | DESIGN INFLUENT COD (MG/L) | DESIGN EFFLUENT COD (MG/L) | CARBON USAGE | |
|---|---|---|---|---|---|
| | | | | (LBS/ GAL) | (KG/CU METER) |
| ACTIVATED SLUDGE | 0.75 | 1000 | 200 | 8.9 | 1780 |
| ALUM COAGULATION | 0.42 | 300 | 150 | 3.0 | 600 |

Based on this isotherm data, preliminary estimates were made of capital and operating costs by ICI America, Inc., and this cost information is presented in Table LXV.

These costs are based on the use of Hydrodarco 3000 in a fixed bed mode with a 217 square foot (20.2 cubic meter) cross sectional area and a 16 foot (4.9 meter) bed depth. Weight of the initial carbon fill was 76,000 pounds (34,776 kiograms) with a 7 percent regeneration at a carbon cost of $0.28 per pound ($0.62 per kilogram). The cost of a filtration system preceeding the adsorption process is not included.

## TABLE LXV

## COST INFORMATION FOR GRANULAR CARBON ADSORPTION SYSTEMS

### CAPITAL COST FOR A 1.25 MGD SYSTEM (1973 DOLLARS)

| CARBON DOSE | | COST |
|---|---|---|
| (LBS/GALS) | (KGMS/CU. METER) | |
| 2.0 | 400 | $636,000 |
| 3.5 | 700 | $676,000 |
| 4.0 | 800 | $681,500 |
| 9.5 | 1900 | $761,000 |

TABLE LXV. COST INFORMATION FOR GRANULAR CARBON ADSORPTION SYSTEMS (CONT'D)

YEARLY OPERATING COST FOR 360 MILLION GALLONS (1.7 MILLION CUBIC METERS) PER YEAR (1973 DOLLARS)

| CARBON DOSE | | | COST PER | | COST PER UNIT OF PRODUCT | |
|---|---|---|---|---|---|---|
| (LBS/ GAL) | (KG/CU METER) | TOTAL COST | (1000 GALLONS) | (CU. METER) | (POUND) | (KG) |
| 2.0 | 400 | $160,000 | $0.44 | $0.12 | $0.005 | $0.011 |
| 3.5 | 700 | $180,000 | $0.50 | $0.13 | $0.006 | $0.013 |
| 4.0 | 800 | $185,000 | $0.51 | $0.14 | $0.006 | $0.013 |
| 9.5 | 1900 | $250,000 | $0.69 | $0.18 | $0.008 | $0.018 |

These costs are for process equipment purchased, installed and owned by BRW. The yearly operating cost for leasing similar equipment including off-site carbon regeneration was estimated at $301,700 by Calgon Corp. using a carbon dose level of 3.0 pounds per thousand gallons. Capital cost was estimated at $25,000 for this approach for non-leasable mechanical and foundation items.

Dosage requirements to achieve the necessary decolorization were found to be too high to permit disposal of the spent carbon. For the 2.0 pounds/1000 gallons (400 kilograms/cu. meter) case, the capital cost would be reduced to a $45,000 but the yearly operating expense would be increased to $310,000 per year or $0.86 per 1000 gallons treated ($227/cubic meter) if the carbon were wasted after exhaustion.

In both cases, carbon was found to provide a method for removing both residual, soluble color and COD but only at a substantial capital and operating investment.

## PART I - RESIN ADSORPTION

An alternative adsorption process for removal of dissolved organics and some inorganics is by the use of a series of resins as the absorbent, and application of the process to textile and dyestuff wastes have been reported in the general literature. A study to evaluate the cost and performance characteristics of this process was undertaken by Rohm and Haas Co and BRW. This study evaluated the process using bench-scale continuous flow equipment to determine the major process parameters.

The studies indicated that the best system for decolorization of the effluent from the activated sludge-alum coagulation system would be a column of a polymeric adsorbent resin (Amberlite XAD-7) followed in series by a column of a weakly basic anion exchange resin amberlite XE-275). The major process parameters were a XAD-7/XE-275 ratio of 2:1, 150 bed volumes of effluent treated per cycle at an influent color level of 200 APHA units, and a flow rate of 16 bed volumes (2 GPM per cubic foot) of resin on line. Performance of the process is summarized in Table LXVI and Figure LXIII.

### TABLE LXVI

### PERFORMANCE OF A RESIN ADSORPTION PROCESS

| | |
|---|---|
| INFLUENT COLOR | 187 APHA |
| COLOR REMOVAL | 79 PERCENT |
| INFLUENT BOD | 22 MG/L |
| BOD REDUCTION | 64 PERCENT |
| INFLUENT COD | 196 MG/L |
| COD REDUCTION | 69 PERCENT |
| INFLUENT FOAM DURATION | 360 SECONDS |
| FOAM DURATION REDUCTION | 98 PERCENT |

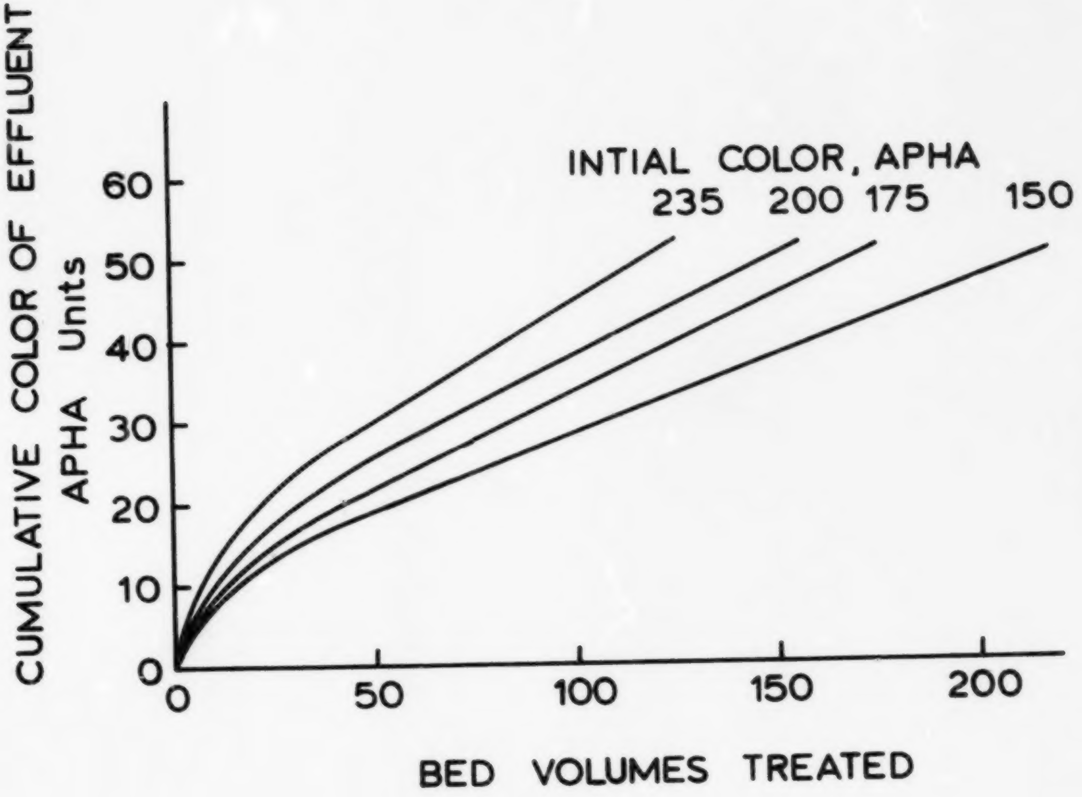


FIGURE LXIII. Color removal by resin adsorption

The results of the study indicate that the process provides excellent removal of residual color, BOD, COD, and foam producing chemicals. If the process were placed in service treating the 200 APHA color units from a two-step alum coagulation process, the 150 bed volumes would be treated before a break through as indicated in Figure LVII.

Spent adsorbent and exchange resins could be regenerated in place as determined by the study. The absorbent would be regenerated by an 80 percent methanol solution, and the colored methanol used to elute the dye from the exchange resin. Additional regeneration of the exchange resin by acid and caustic treatment would also be required.

The methanol-dye mixture would be sent to a small still for recovery of the methanol, and the still "bottoms" would be evaporated prior to incineration and land disposal by others.

Cost information for the process is presented in Table LXVII. These costs do not include a filtration step prior to the adsorption process.

## TABLE LXVII

## SUMMARY OF COST INFORMATION FOR A RESIN ADSORPTION PROCESS

| | |
|---|---|
| CAPITAL COST FOR 1.25 MGD PROCESS (1973 DOLLARS) | $836,000 |
| YEARLY OPERATING COST FOR A PROCESS | |
| TREATING 360 MILLION GALLONS (1.14 MILLION CUBIC METERS) PER YEAR (1973 DOLLARS) | |
| TOTAL | $171,700 |
| TOTAL PER THOUSAND GALLONS TREATED | $0.48 |
| TOTAL PER CUBIC METER TREATED | $0.13 |
| TOTAL PER KILOGRAM OF PRODUCT | $0.013 |
| TOTAL PER POUND OF PRODUCT | $0.006 |

## PART J - MONITORING

Several experiments were made during the course of the study to evaluate quick response methods of wastewater analyses.

First, TOC measurements were made once a month of the various plant effluents and compared with BOD and COD values. For BOD, no correlation was found, but for COD a reasonable correlation of $\text{TOC} = 0.25\ \text{COD}$ was determined.

Second, over a two month period, optical density (O. D.) was compared to alum coagulation effluent suspended solids and a reasonable correlation of $\text{TSS} = [(\text{O.D.})\ (650) - 10]$ was determined.

# SECTION XVI

# CHARACTERISTICS OF THE RECEIVING STREAM

During the study, samples were regularly taken from Martins Creek above the BRW discharge for analysis. This data is presented in Table LXVIII.

# TABLE LXVIII

## ANALYSIS OF MARTINS CREEK WATER ABOVE BRW

| PARAMETER | AVERAGE VALUE |
|---|---|
| CRITICAL FLOWS | |
| 7 DAY, 10 YEAR | 0.5 CFS (0.01 CMS) |
| SPRING AVERAGE | 27.7 CFS (0.78 CMS) |
| SUMMER AVERAGE | 5.4 CFS (0.15 CMS) |
| FALL AVERAGE | 5.3 CFS (0.15 CMS) |
| WINTER AVERAGE | 14.2 CFS (0.40 CMS) |
| CONTAMINANTS | |
| TEMPERATURE | |
| HIGH | 20°C |
| LOW | 2°C |
| PH | 7.4 |
| DISSOLVED OXYGEN | 9.4 MG/L |
| ALUMINUM | 0.13 MG/L |
| CALCIUM | 32.8 MG/L |
| CHROMIUM | .005 MG/L |
| COPPER | N.D. |
| IRON | 0.125 MG/L |
| MAGNESIUM | 5.15 MG/L |
| NICKEL | N.D. |
| POTASSIUM | 1.375 MG/L |
| SODIUM | 6.67 MG/L |
| ZINC | 0.004 MG/L |
| MERCURY | 0.2718 MG/L |
| PHOSPHATE | 0.5 MG/L |
| BOD | 10 MG/L |
| COD | 7 MG/L |
| COLOR | 19 APHA |
| TURBIDITY | 2 JTU |

# SECTION XVII

# REFERENCES

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# SECTION XVIII

# APPENDICES

A. TABULATION OF PRODUCTION CHEMICAL USAGE

B. TABULATION OF PRODUCTION DYE USAGE

C. SUMMARY OF ANALYTICAL METHODS

D. LABORATORY QUALITY CONTROL DATA

E. PROCEDURE FOR BATCH ACTIVATED SLUDGE TREATABILITY STUDIES

F. PROCEDURE FOR BATCH ALUM COAGULATION TREATABILITY STUDIES

G. PROCEDURE FOR LEACHATE STUDY

H. PROCEDURE FOR STATIC BIOASSAY

I. PROCEDURE FOR MULTIPLE DILUTION BOD

J. CONVERSION TABLE

# APPENDIX A

## TABLE A-I

## TABULATION OF PRODUCTION CHEMICAL USAGE

| CHEMICAL | PERCENT OF YEARLY TOTAL |
|---|---|
| CARRIER NT | 18.4 |
| AEROTEX WATER REPELLENT | 5.7 |
| SOLVECREST RB | 5.4 |
| CAP LEV ME | 4.9 |
| OAK-SCOUR SO-50 | 4.3 |
| ACETIC ACID | 4.2 |
| MONOSODIUM PHOSPHATE | 4.1 |
| SUB-TOTAL | 47.0 |
| AVITONE F | 3.5 |
| CAUSTIC SODA | 3.3 |
| CALGON | 3.2 |
| NEUTROL #9 | 3.1 |
| ROLLER CLEANER | 2.9 |
| CAP LUBE LSP | 2.7 |
| SODIUM HYDROSULPHITE | 2.3 |
| HERRITON SWD | 2.3 |
| OAKSPERSE AD-40 | 2.3 |
| SANDOPAN DTC | 2.2 |
| CAP CARRIER BB | 2.2 |
| FORMIC ACID | 2.2 |
| RACOFIX NY | 2.1 |
| SOAP OFF 60 | 2.0 |
| AMMONIUM CHLORIDE | 1.6 |
| ANTIFUME GFD | 1.5 |
| OAKAPON X-70 | 1.4 |
| FANTAPON X-70 | 1.2 |
| WINKLER FINISH NO. 1 | 1.2 |
| OAK LEV NU9 | 1.1 |
| DISPERSING AGENT | 1.0 |
| GLUCONIC ACID | 1.0 |
| INTRAWITE EBF | 1.0 |
| NEOPORT DB6 | 0.9 |
| LYOGEN P | 0.9 |
| RESIN CP | 0.8 |
| SUB-TOTAL | 96.9 |
| OTHER | 3.1 |
| TOTAL | 100.0 |

TOTAL USAGE: 2,500,000 POUNDS (1,135,000 KILOGRAMS) PER YEAR

# APPENDIX B

## TABLE B-I

## TABULATION OF PRODUCTION DYE USAGE

| DYESTUFF | CLASS | PERCENT OF YEARLY TOTAL |
|---|---|---|
| EASTMAN BLACK T | D | 10.2 |
| LATYL BRILLIANT BLUE BGN | D | 7.8 |
| AMACEL BLUE GP | D | 7.3 |
|  | SUB-TOTAL | 25.3 |
| AMACRON BRILLIANT BLUE G | D | 3.1 |
| TERASIL NAVY BLUE SGL | D | 2.8 |
| INTRALAN BLACK BGL | A | 2.4 |
| PALACET RED GFL | D | 2.1 |
| RESOLIN BRILLIANT YELLOW 76L | D | 2.2 |
| CALCOSPERSE RED 5G | D | 2.2 |
| ALIZARINE FAST GREEN CGN | A | 2.1 |
| CALCOSPERSE BLUE | D | 2.0 |
|  | SUB-TOTAL | 44.2 |
| FORON YELLOW-BROWN S-2RFT | D | 1.5 |
| LANASYN YELLOW 24L | A | 1.6 |
| LANASYN BLACK BGL | A | 1.6 |
| AMACEL VIOLET 34-GLF | D | 1.6 |
| LANASYN RED 2GL | A | 1.4 |
| ALIZARINE LIGHT BLUE 3FR | A | 1.3 |
| AMACEL FAST YELLOW 24-GLF | D | 1.2 |
| POLYSPERSE YELLOW WGLW | D | 1.1 |
| LANASYN ORANGE RL | A | 1.0 |
| TERASIL BLACK PR | D | 1.0 |
| NYLON FAST BLACK BRW | A | 1.0 |
| AMACRON DIAZOIC BLACK JB | D | 1.0 |
| VITROLAN BLACK WA | A | 1.0 |
| INTRASPERSE DARK BLUE RB | D | 1.0 |
| CALCOSPERSE RED 4GR | D | 0.9 |
| INTRASPERSE BLUE GREEN C | D | 0.9 |
| PALANIL RUBIN FL | D | 0.8 |
| SODYECRON BRILLIANT VIOLET B5R | D | 0.8 |
| CALCOSPERSE RED GF | D | 0.8 |
| RESOLYN BR YELLOW P8 GLN | D | 0.7 |
| IRGALAN YELLOW 2GL | A | 0.7 |
|  | SUB-TOTAL | 67.1 |
|  | OTHER | 32.9 |
|  | TOTAL | 100.0 |

TOTAL USAGE: 295,000 POUNDS (134,000 KILOGRAMS) PER YEAR

NOTE: D = DISPERSE A = ACID

# APPENDIX C

# SUMMARY OF ANALYTICAL METHODS

Routine Analyses in the BRW Laboratory

1. Alkalinity and Acidity

   Potentiometric method as described in Standard Methods For the Examination of Water and Wastewater (13th Edition)

2. Biochemical Oxygen Demand

   Five day incubation method as described in Standard Methods

3. Chemical Oxygen Demand

   Dichromate Reflux method as described in Standard Methods

4. Color

   Absorbtion measurement using a filter photometer (Hach AC-DR) to give results in terms of the Standard Methods cobalt-platinum scale. Samples were filtered through Whatman Number Five paper or Reeve Angel 934AH glass fiber filter discs and compared with distilled water. A calibration curve for the instrument is presented in Figure C-I. This curve shows a substantial divergence from standard beginning at a value of 250, and for this reason samples were diluted to give readings in the 0-250 range.

5. Dissolved Oxygen

   Membrane electrode method as described in Methods for Chemical Analysis of Water and Wastes (1971 Edition)

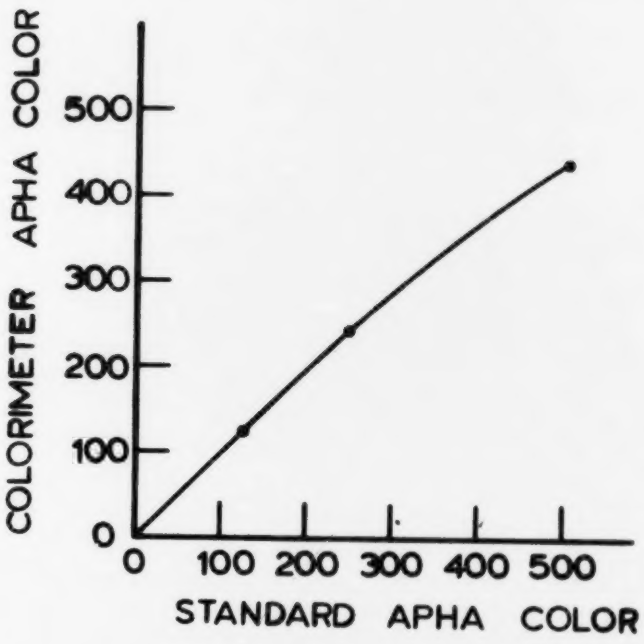

FIGURE C-1. Calibration curve for Hach Colorimeter

6. Nitrogen

Measurement of soluble ammonia nitrogen using the direct nezzlerization method with absorbance measurement using a filter photometer. Samples were filtered through Whatman Number Five paper or Reeve Angel 934AH glass fiber filter discs.

7. Phosphorous

Measurement of soluble orthophosphate using the single reagent method with absorbance measurement using a filter photometer samples were filtered through Whatman Number Five paper or Reeve Angel 934AH glass fiber filter discs.

8. pH

Electrometric method as described in Standard Methods

9. Solids, Dissolved and Suspended

Glass fiber filter (Reeve Angel 934AH) methods as described in Methods For Chemical Analysis

10. Surfactants

Measurement of soluble anionic surfactants using the methylene blue method with absorbance measurement using a filter photometer. Samples were filtered through Whatman Number Five paper or Reeve Angel 934AH glass fiber filter discs.

11. Turbidity

Measurement of turbidy using absorbance measurement with a filter photometer. Samples of waste were compared with a standard prepared by filtering the waste through filter paper of filter discs.

Monthly Analyses By Pollution Control Science, Inc.

1. Metals

   Atomic absorption spectrophotometric method as described in Methods For Chemical Analysis using a Perkin-Elmer #305 with a carbon rod attachment

2. Total Organic Carbon

   TOC method as described in Methods For Chemical Analysis using a Beckman 915 Analyzer.

3. Hexavalent Chromium

   S-Dyphenylcarbazide method as described in Standard Methods

4. Sulfate

   Turbimetric method as described in Standard Methods

5. Chloride

   Mercuric nitrate method with potentiometric titration as described in Standard Methods

6. Nitrate

   Phenoldisulfonic method as described in Standard Methods

7. Nitrite

   Diazotization method as described in Standard Methods

8. Cyanide

   Distillation followed by colorimetric analysis as described in Standard Methods

9. Phenol

   Distillation followed by colorimetric analysis as described in Standard Methods

10. Oil and Grease

Sokhlet extraction method as described in Standard Methods

11. Total Hydrocarbon

EPA procedure proposed by Region II Laboratory using an infrared scan (2600 $cm^{-1}$ to 3200 $cm^{-1}$) of a carbon tetrachloride extraction of the sludge

12. Digestion of sludges and sediment

Samples of sludge and sediment were digested using warm nitric and hydrochloric acids

# APPENDIX D

## TABLE D-I - LABORATORY QUALITY CONTROL CHECK USING SPIKED SAMPLES

| CONTAMINANT (MG/L) | SAMPLE NUMBER 1 ANALYSIS | ACTUAL | 2 ANALYSIS | ACTUAL | 3 ANALYSIS | ACTUAL |
|---|---|---|---|---|---|---|
| ALUMINUM | 5 | 25 | 585 | 575 | 1185 | 1100 |
| CHROMIUM | 0 | 9.2 | 45 | 83 | 300 | 406 |
| COPPER | 2 | 9.0 | 53 | 67 | 302 | 314 |
| IRON | - | 18 | 295 | 402 | 640 | 769 |
| LEAD | 30 | 28 | 80 | 92 | 300 | 350 |
| ZINC | 10 | 20 | 95 | 79 | 395 | 367 |

# TABLE D-2

## LABORATORY QUALITY CONTROL CHECK USING SPLIT SAMPLES

| CONTAMINANT (MG/L) | BRW ANALYSIS | | EPA ANALYSIS | |
|---|---|---|---|---|
| | RAW WASTE | FINAL EFFLUENT | RAW WASTE | FINAL EFFLUENT |
| CHROMIUM | 110 | 150 | 100 | 150 |
| COPPER | 5 | 20 | 10 | 20 |
| IRON | 400 | 410 | 610 | 620 |
| LEAD | <1 | 30 | 1 | 30 |
| MERCURY | 1 | <0.5 | 10 | <0.5 |
| NICKEL | <20 | <50 | <20 | <50 |
| ZINC | 150 | 155 | 80 | 70 |

# APPENDIX E

# PROCEDURE FOR BATCH ACTIVATED SLUDGE TREATABILITY STUDIES

I. Preparation of Initial Batch Mixture

   A. Dewatered Sludge

      1. The sludge used was obtained from either the acclamated mixed liquor of the lab scale bio-oxidation unit or from the full-scale activated sludge system.

      2. The sludge was filtered through a Buchner funnel with a cloth filter until the sludge was concentrated enough to be scraped and collected with a spatula.

      3. Approximately 75 grams was needed to yield a suspended solids concentration of 3000 mg/l in the two liter volume of the graduate cylinder used as the reaction vessel.

   B. Chemical Solution

      1. The concentration of solution needed to obtain an initial COD of about 1000 mg/l was estimated from preliminary COD data.

      2. Two liters of solution at the strength determined above were prepared and adjusted to final pH (6.0 - 8.0) if necessary.

      3. The dewatered sludge was diluted with the prepared chemical solution to the two liter mark.

II. Reactor Operations

   A. Mixing using a magnetic stirring apparatus and aeration with compressed air and an air diffuser were used to produce a uniform mixture.

   B. Sampling was done at near mid-height of the reaction vessel at timed intervals of 0 hour (initial), 2 hr., 4 hr., and 22 hrs.

   C. Surface sludge and foam build-up was periodically scraped back into the solution.

   D. Aeration rates were decreased if foaming persisted.

# APPENDIX F

## PROCEDURE FOR BATCH ALUM COAGULATION TREATABILITY STUDIES

Jar tests were performed using paddle stirring equipment for mixing and a pH meter to measure pH during the coagulation process. Stock solutions of alum, caustic, and polymer were prepared at 1%, 5%, and 0.1% respectively.

For the single coagulation process, the "Standard Jar Test" procedure was used:

1. Add 400 ppm alum during rapid mix at 80-100 rpm for 1 - 3 minutes
2. Adjust pH during rapid mix with caustic soda
3. Add 5 ppm polymer during slow mix at 40 - 45 rpm for 5 - 10 minutes
4. Settle
5. Decant and Analyze

For the two-step coagulation process the "Two-Step Jar Test" procedure was used:

Step One

1. Add 400 ppm alum during rapid mix at 80 - 100 rpm for 1 - 3 minutes
2. Adjust pH during rapid mix with caustic soda
3. Add 5 ppm polymer during slow mix at 40 - 45 rpm for 5 - 10 minutes
4. Settle
5. Decant and Use in Step Two

Step Two

1. Adjust pH of decanted supernatant of Step One to pH = 6.5 or pH = 7.5 during rapid mix at 80-100 rpm for 1 - 3 minutes
2. Settle
3. Decant and Analyze

# APPENDIX G

## PROCEDURE FOR LEACHATE STUDY

In order to determine leachate characteristics under approximate landfill conditions, a column leaching study was conducted. Dewatered sludge was placed in a 4 inch (10 cm) diameter PVC column to a depth of 5 inches (13 cm). The sludge was supported by a 2 inch (5 cm) layer of sand and gravel. Distilled water was then applied to the surface of the sludge at the rate of 220 mls per day. The leachate was collected daily and analyzed periodically.

Initially, the sludge would not percolate the applied water. As a result, the sludge was removed and put through a single freeze/thaw cycle. This treatment resulted in satisfactory percolation.

# APPENDIX H

## PROCEDURE FOR STATIC BIOASSAY

For the purpose of determining relative toxicity of sludge cake leachate, brief static bioassays were conducted. The leachate was diluted to the appropriate concentration using tap water. One gallon was used as the test volume, and five gold fish obtained from a local pet store were placed in each test vessel. The solutions were aerated throughout the test and the dissolved oxygen concentration maintained at 8 mg/l or greater. Temperature was maintained at 70°F ± 2°F. Fish were removed from each container as soon as immobilization or death was noted.

# APPENDIX I

## PROCEDURE FOR MUTLIPLE DILUTION BOD

The multiple dilution BOD procedure was performed to determine the threshold toxicity level of a substance. The threshold toxicity level is the concentration of the substance at which a depressed biological oxidation rate is first detected. The toxicity observation reflects acute effects on the seed organism.

The procedure was as follows:

1. Prepare a series of BOD bottles with increasing concentration of test material.
2. Add about 3.0 ml of equalized raw wastewater to each bottle as a control. One bottle should contain the same amount of seed.
3. Prepare at least three blank samples for each test series
4. Neutralize the sample before filling each bottle with dilution water.
5. Incubate at 20°C for three days.
6. Record initial and residual D. O. readings.
7. Plot data by percent volume of test material versus D. O. mg/l.

## TECHNICAL REPORT DATA

*(Please read Instructions on the reverse before completing)*

| | | |
|---|---|---|
| 1. REPORT NO.<br>EPA-600/2-75-055 | 2. | 3. RECIPIENT'S ACCESSION NO. |
| 4. TITLE AND SUBTITLE<br>Treatment of Textile Wastewater by Activated Sludge and Alum Coagulation | | 5. REPORT DATE<br>October 1975<br>6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S)<br>Thomas L. Rinker | | 8. PERFORMING ORGANIZATION REPORT NO. |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>Blue Ridge-Winkler Textiles<br>Division of Lehigh Valley Industries, Inc.<br>High and Kline Streets<br>Bangor, Pennsylvania 18013 | | 10. PROGRAM ELEMENT NO.<br>1BB036; ROAP 21AZT-006<br>11. CONTRACT/GRANT NO.<br>S801192 |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br>EPA, Office of Research and Development<br>Industrial Environmental Research Laboratory<br>Research Triangle Park, NC 27711 | | 13. TYPE OF REPORT AND PERIOD COVERED<br>Final; 8/22/72-5/31/75<br>14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES Project officer is Thomas N. Sargent, EPA, Environmental Research Laboratory, College Station Road, Athens, GA 30601.

16. ABSTRACT The report gives results of a study of the treatment of wastewater, from a textile mill producing synthetic knit fabric for the apparel and automotive markets, with a system combining biological (activated sludge) and chemical (alum coagulation) processes. The treatment consisted of: heat recovery; equalization; completely mixed activated sludge with sedimentation and nutrient supplement; and alum coagulation with sedimentation, polymer addition, and pH adjustment. The activated sludge process effectively removed degradable organics and ammonia nitrogen. The alum coagulation process effectively removed colloidal organics, suspended solids, orthophosphate, and certain metals. Total treatment system removals for BOD, COD, and color were 92, 73, and 69 percent, respectively. Capital cost of the system was $1.15 million with a yearly operating expense of $269,030, including capital cost depreciation. Additional treatment was required to meet anticipated discharge limitations. Appropriate research studies were conducted using carbon adsorption, resin adsorption, and ozonation for residual, soluble color removal.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| *Water Pollution, *Sludge, *Industrial Wastes, *Coagulation, *Textile Processes, Waste Water, Waste Treatment, Heat Exchangers, Equalizing, Aerobic Processes, Alums, Neutralizing, Polyelectrolytes, Color, Decoloring | *Activated Sludge<br>*Sludge Treatment<br>*Textile Wastewater Treatment<br>*Physical/Chemical Treatment<br>Secondary Treatment | 13B, 07A<br>07D<br>13H<br>13A<br>06C, 07B<br>20F |
| 18. DISTRIBUTION STATEMENT<br>Unlimited | 19. SECURITY CLASS *(This Report)*<br>Unclassified | 21. NO. OF PAGES<br>216 |
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